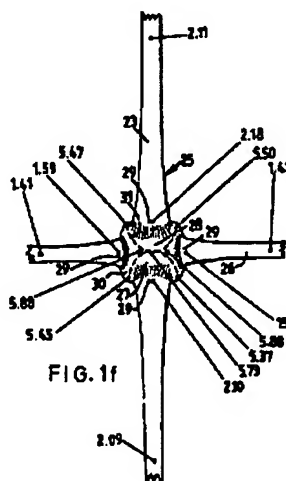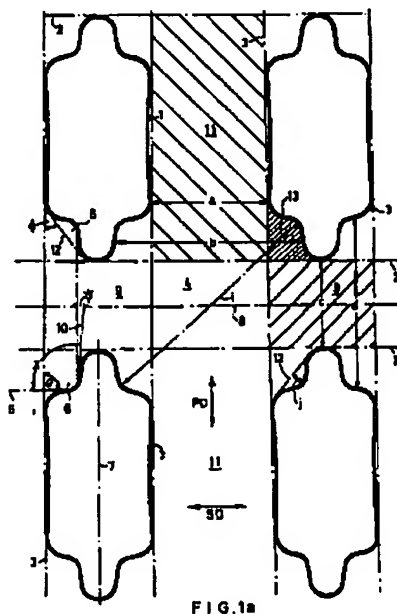|	
(21) Application No 9524112.1	(51) INT CL[6] B29D 28/00
(22) Date of Filing 24.11.1995	
(30) Priority Data (31) 9423721 (32) 24.11.1994 (33) GB	(52) UK CL (Edition O) B5A AD31 A1R314C1C A1R400 A1R455 A20T16 U1S S1701 S1702 S1760
	(56) Documents Cited GB 2256164 A GB 2174332 A
(71) Applicant(s) Netlon Limited (Incorporated in the United Kingdom) Kelly Street, Mill Hill, BLACKBURN, Lancashire, BB2 4PJ, United Kingdom	(58) Field of Search UK CL (Edition N) B5A AD31 INT CL[6] B29C 55/14 , B29D 28/00 Online:WPI
(72) Inventor(s) Frank Brian Mercer Keith Fraser Martin Stuart Green Nigel Edwin Wrigley	(74) Agent and/or Address for Service Marks & Clerk 57-60 Lincoln's Inn Fields, LONDON, WC2A 3LS, United Kingdom

(54) **Plastics material mesh structures**

(57) In order to provide wider biaxially-stretched geogrids having high primary direction (PD) strength, crotch-forming zones of a starting material which is at least 2.0 mm thick have protuberances 6. On stretching, PD orientation passes right through the junction 27 but the protuberance 6 causes the orientation ratio of the crotch edge to decrease significantly as orientation enters the central part of the crotch edge. After a secondary direction stretch of at least about 1.5:1, the thickness of the central part of the crotch edge is not reduced by more than about 20%. The stretching does not reduce the thickness of any point along notional ridge lines 31 to such an extent that the ratio of finished thickness to starting thickness at that point is less than about 80% of the ratio of finished thickness to starting thickness of the junction mid-point. In the biax geogrid 25, the junction mid-point is significantly thicker than the PD strand mid-point. The thickest part of the crotch is greater than about 80% of the thickness of the mid-point of the junction 27. The junction 27 has a generally square or rectangular central zone with narrow projections 28 at the corners extending outwards to the crotch edges.

FIG. 1a

FIG. 1f

GB 2 295 353 A

F I G. 1a

FIG. 1b

FIG. 1c

FIG.1d

2.13

22

5.52

5.70

5.91

5.94

5.37

2.10

5.52

2.18

5.94

5.93

5.53

2.12

23

2.11

23

5.47

1.59

1.41

29

31

2.18

25

5.50

1.41

28

29

29

30

27

29

26

5.88

5.45

151

5.88

5.37

5.73

2.10

FIG. 1f

2.09
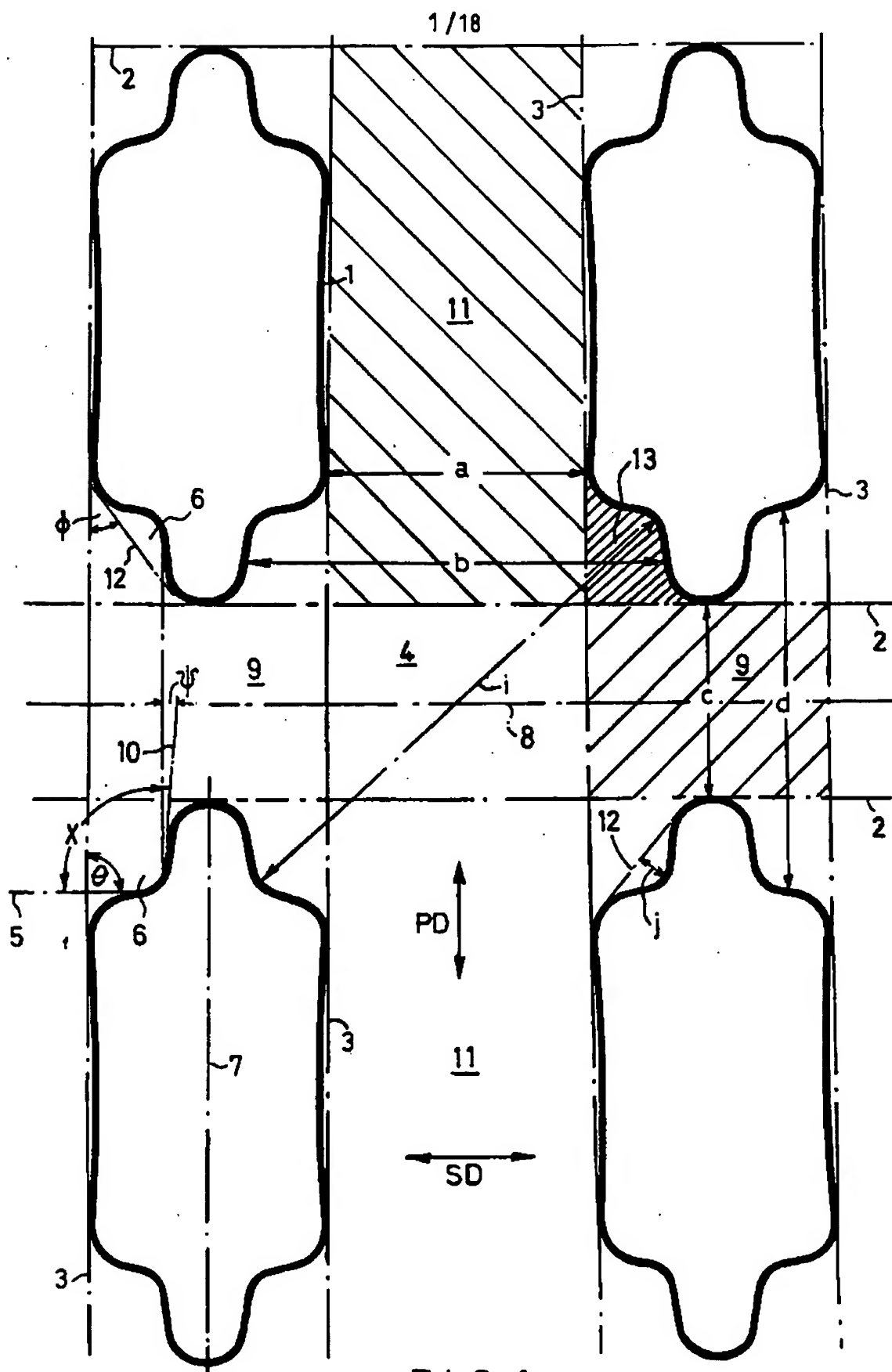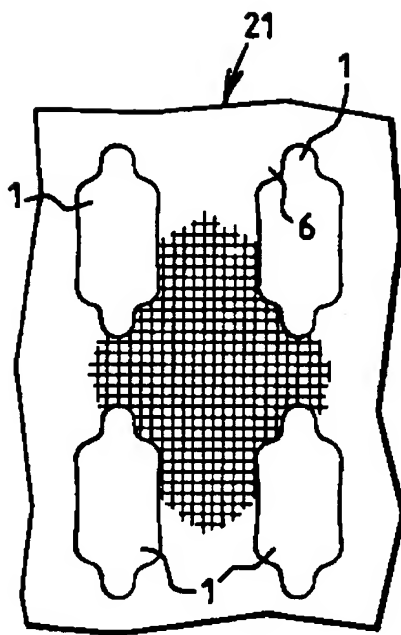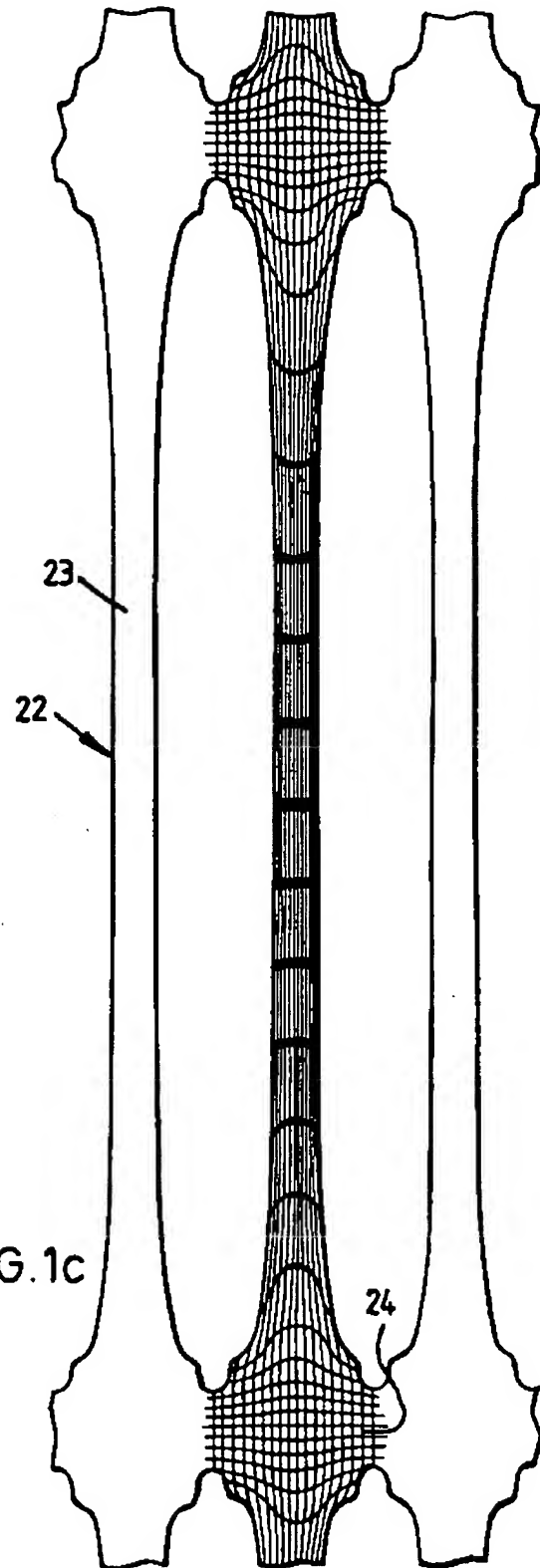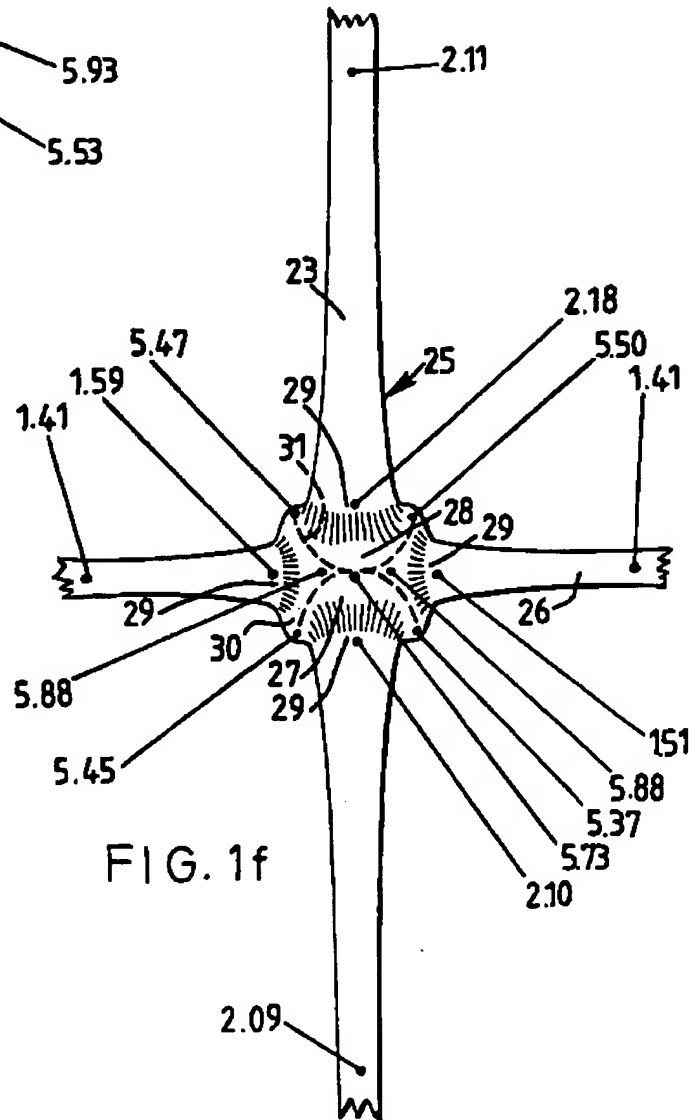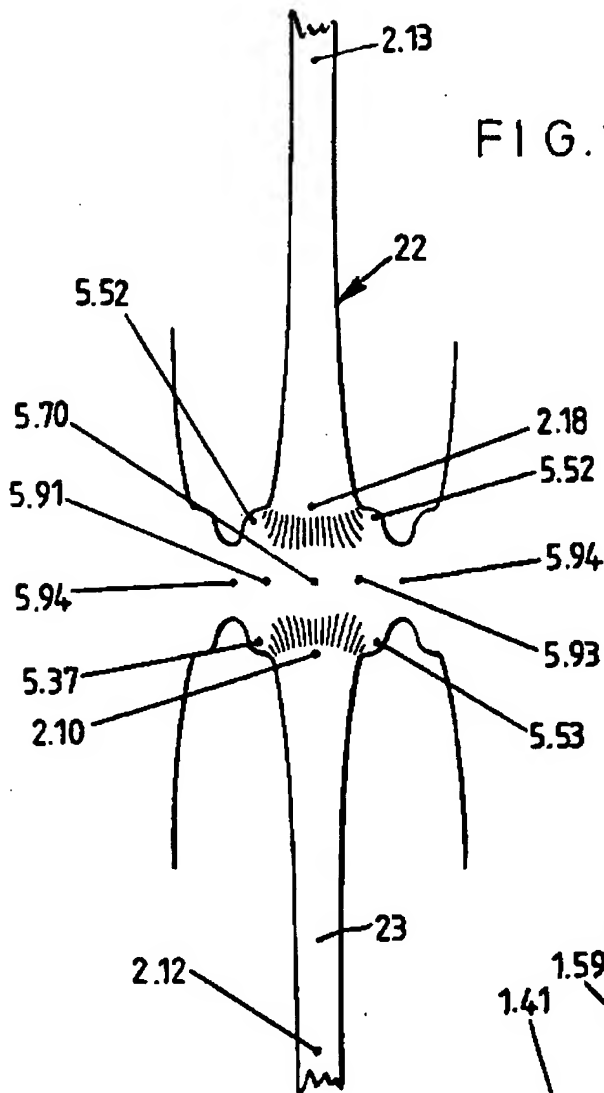
F I G . 1e
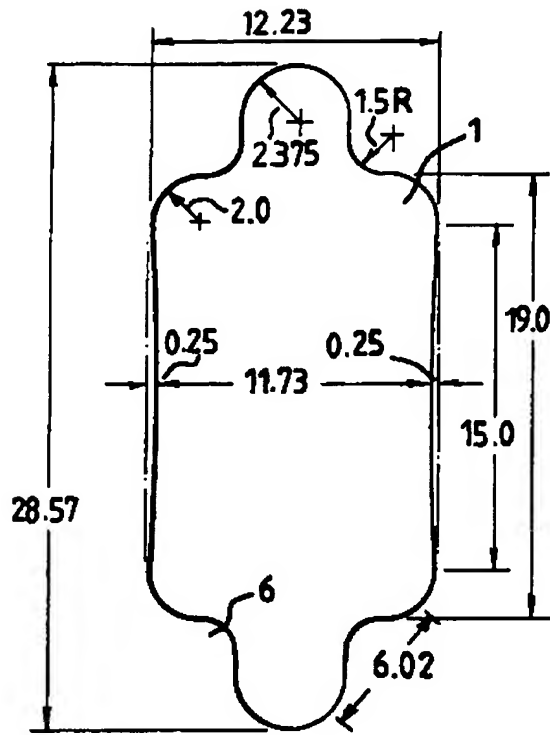
FIG.1g

FIG.2

F I G . 3

F I G . 4

FIG.5

FIG.6
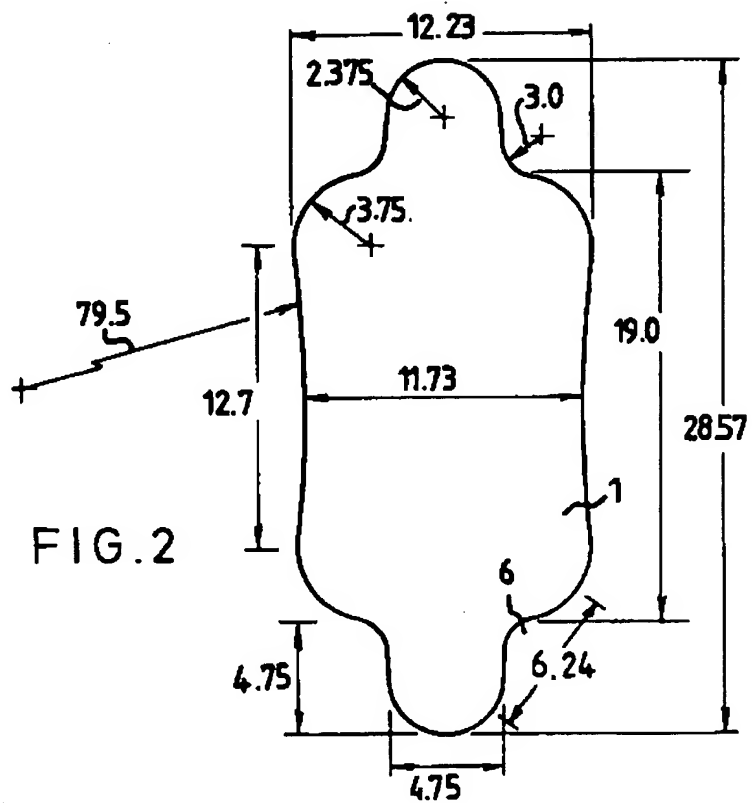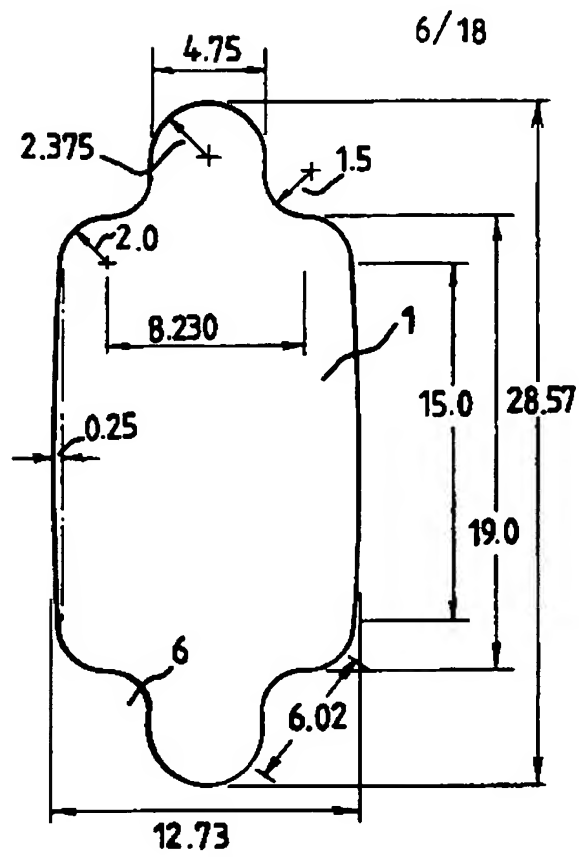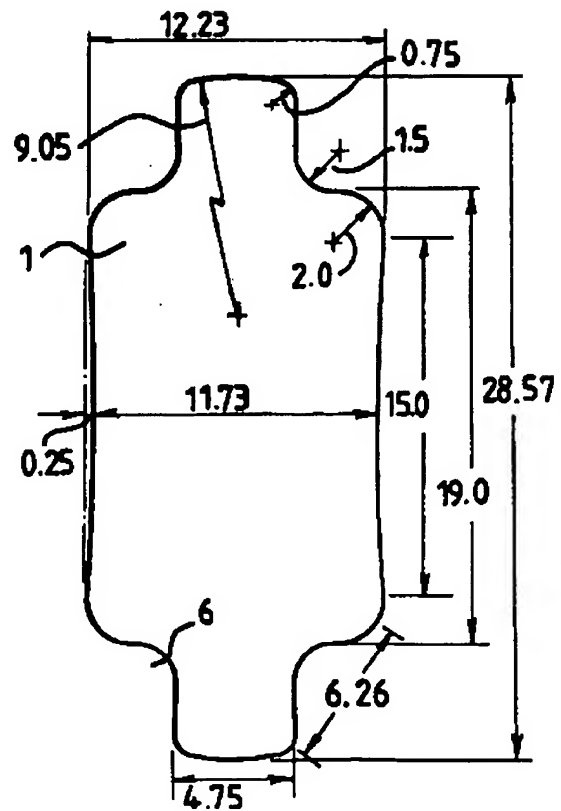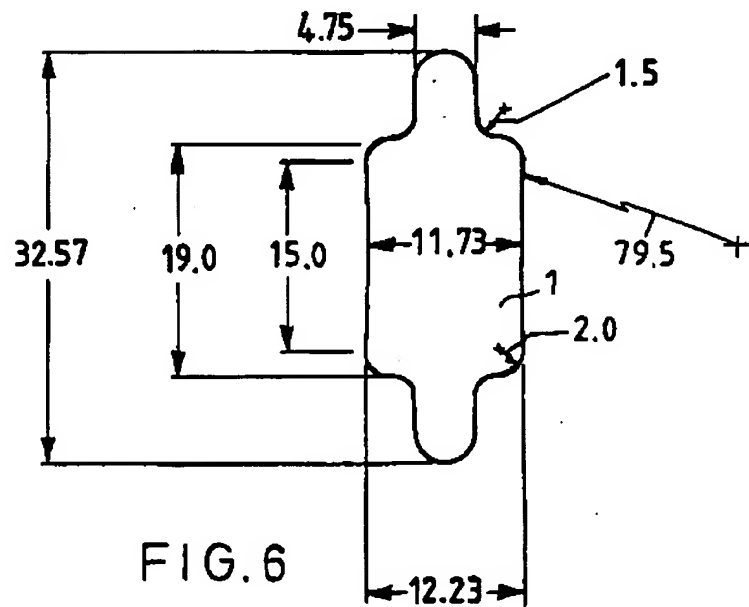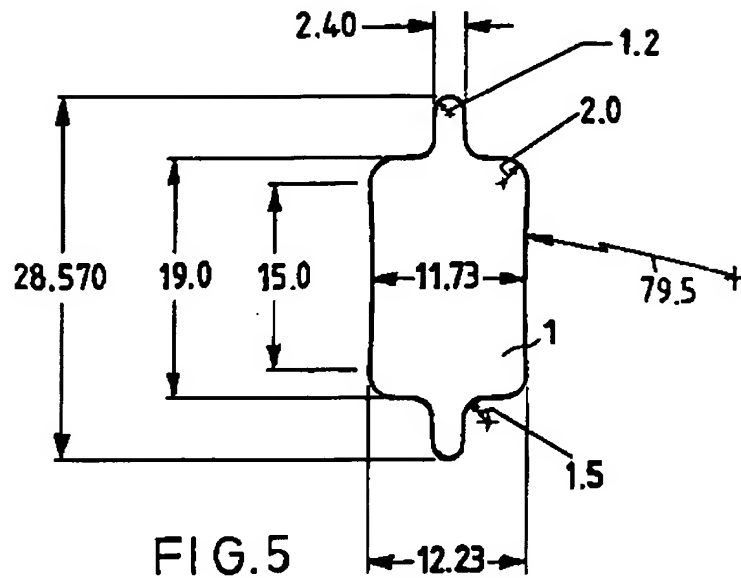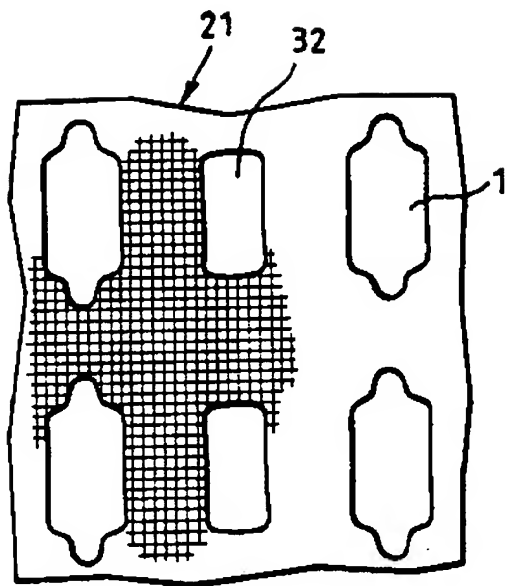
FIG.7a

FIG.7b

FIG.7c

FIG.7d

FIG.7e

FIG.7f
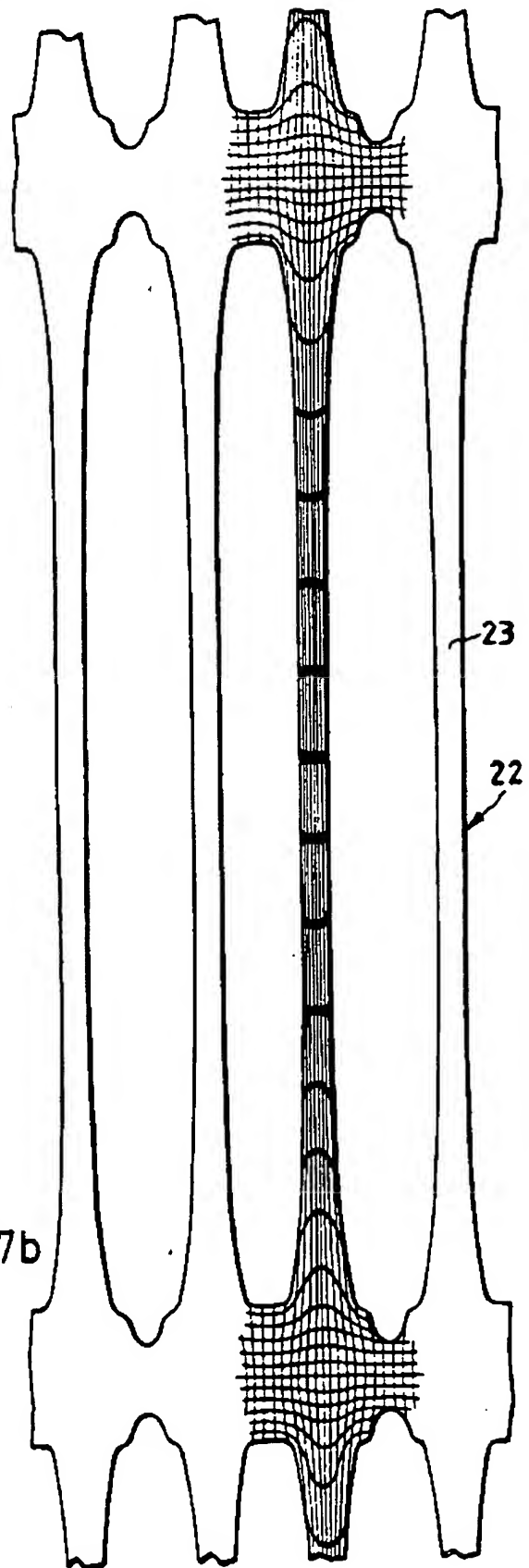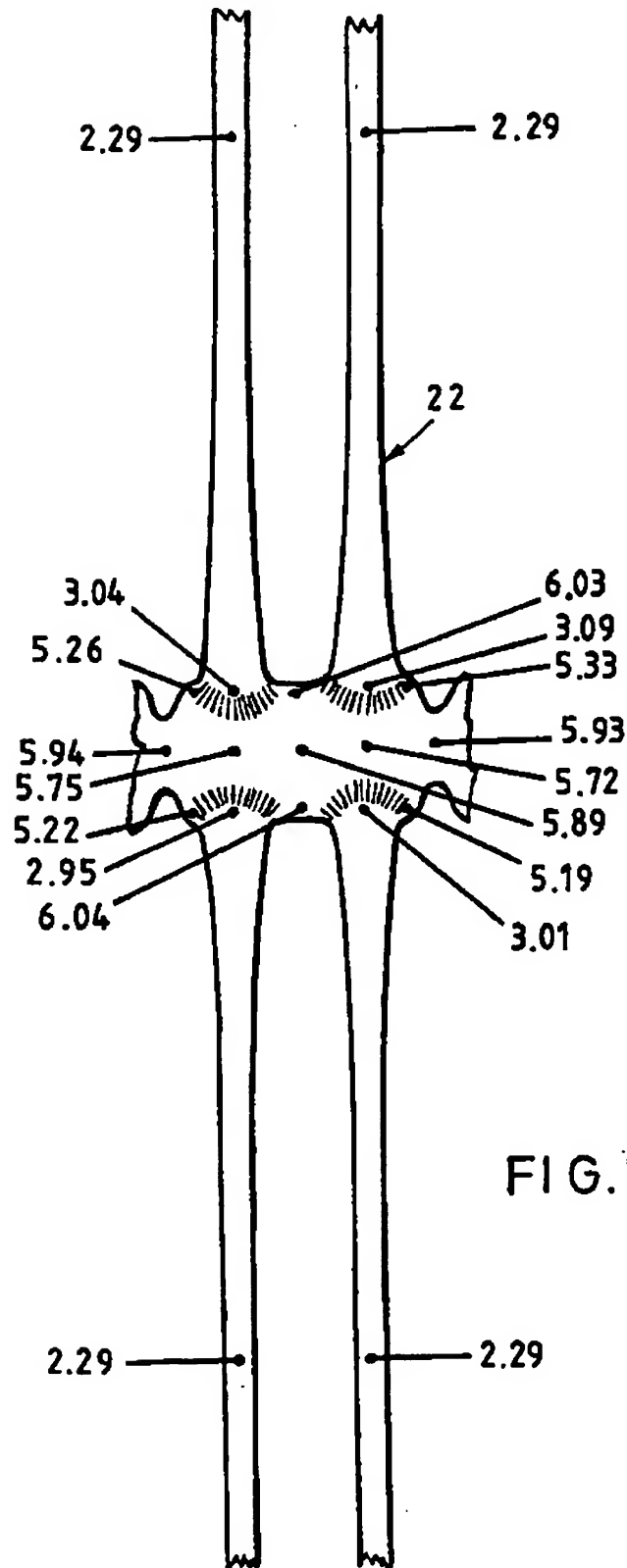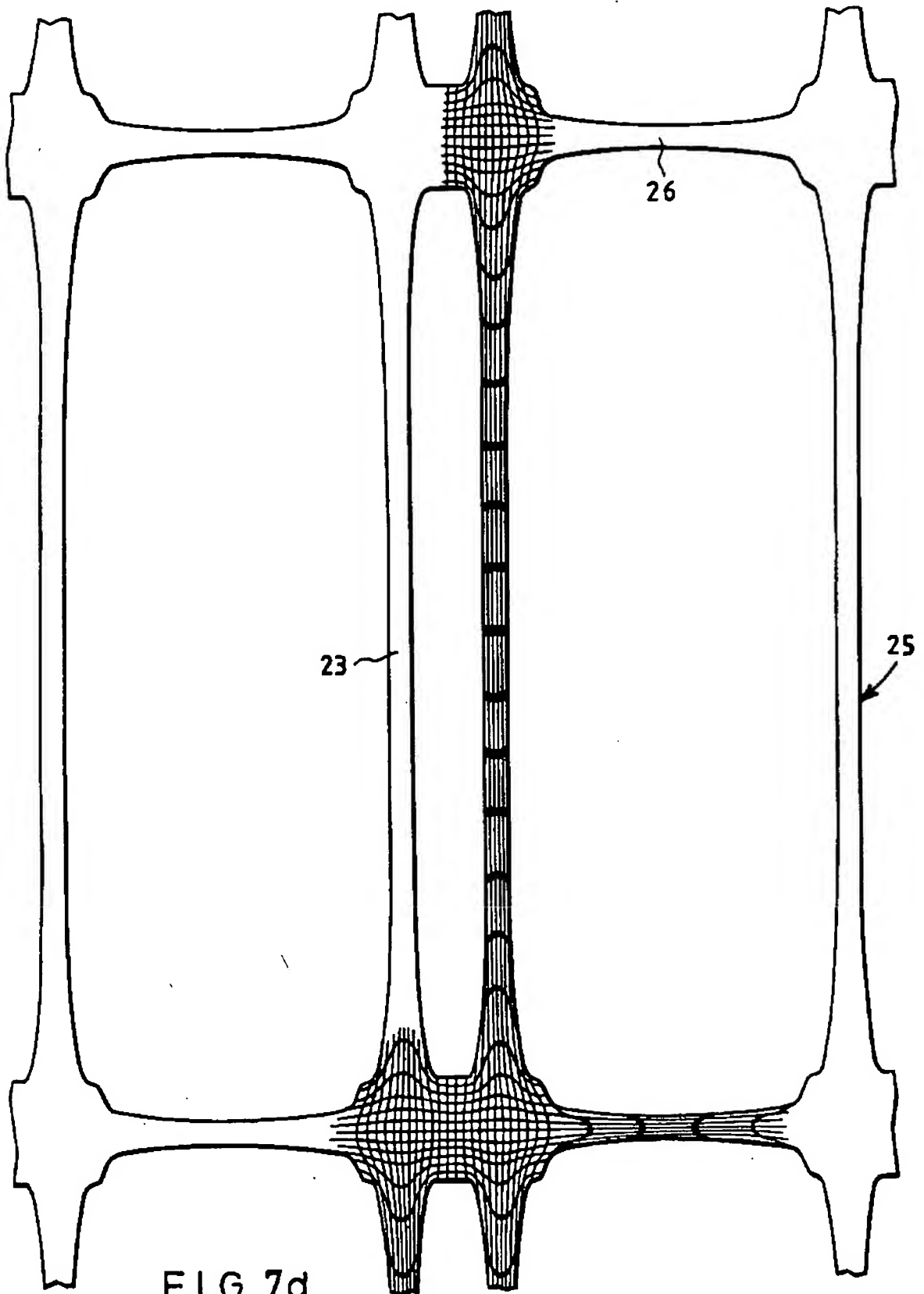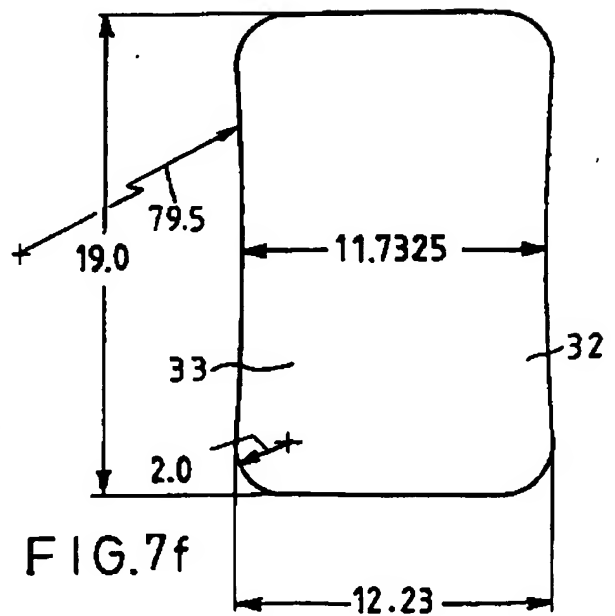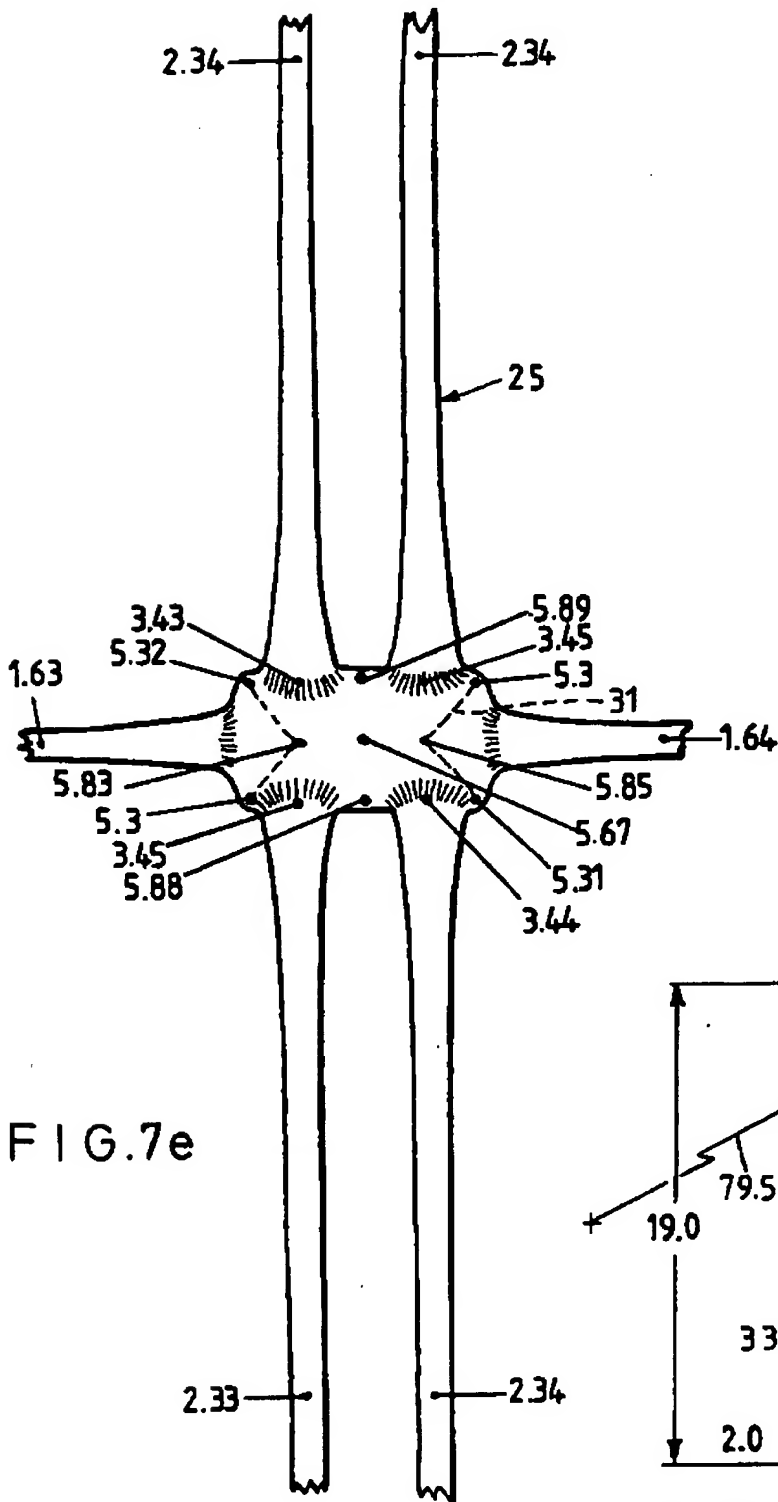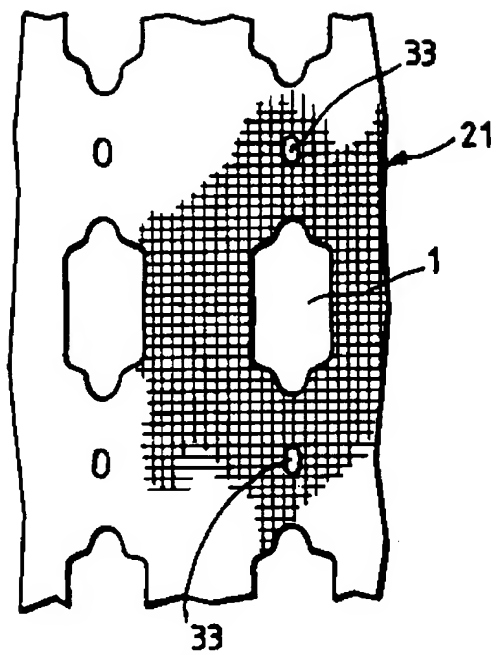
FIG. 8a

FIG.8b

FIG. 8c

FIG. 8d
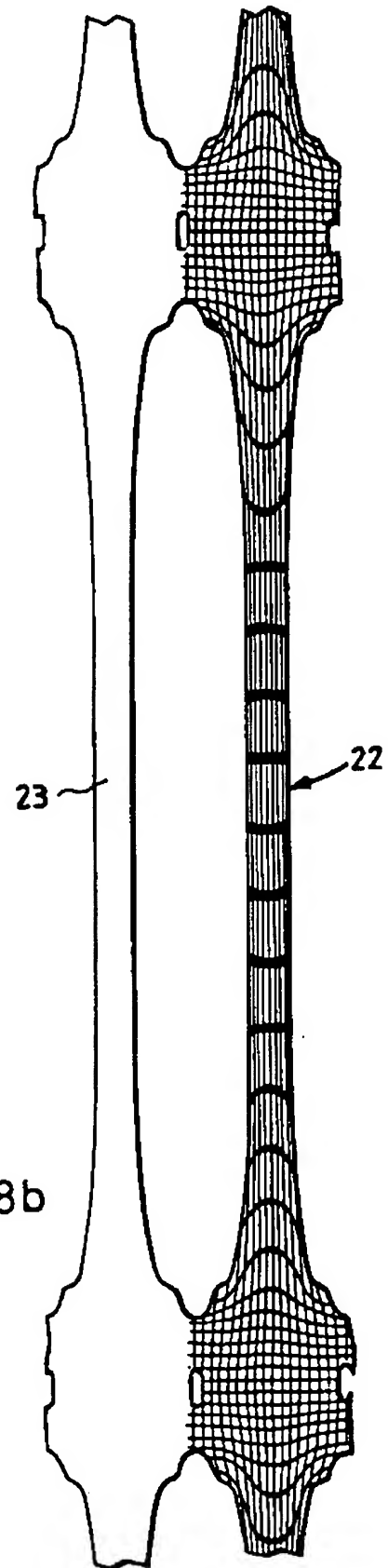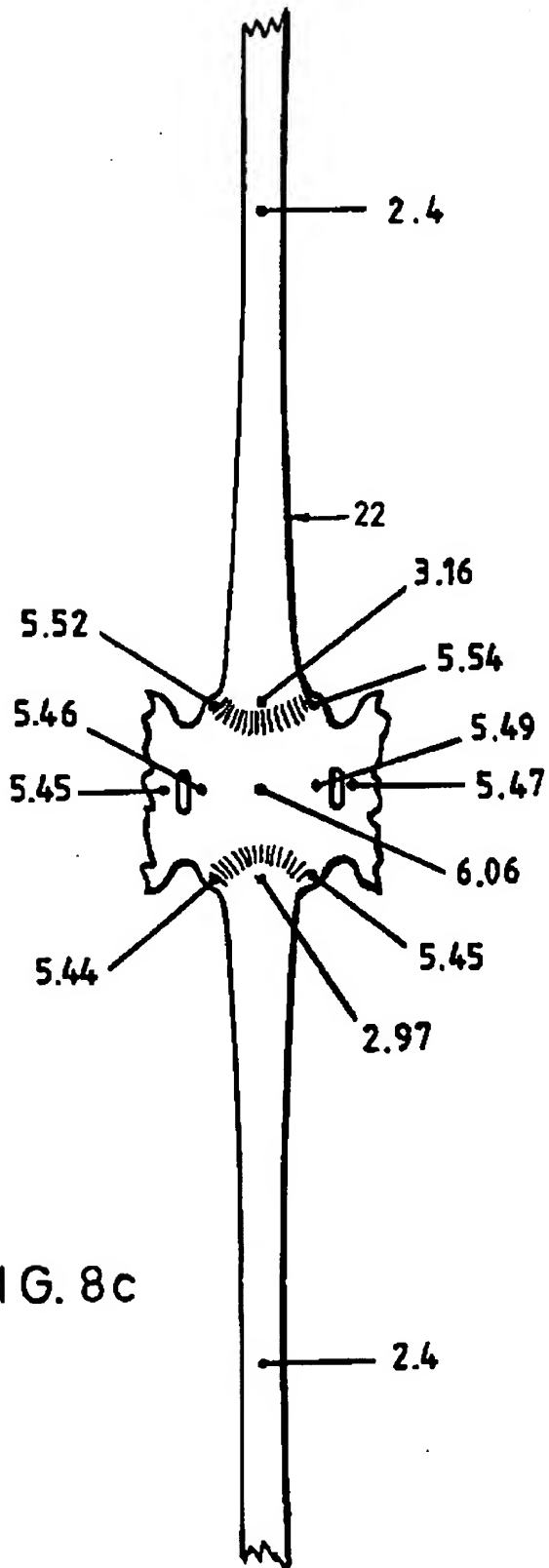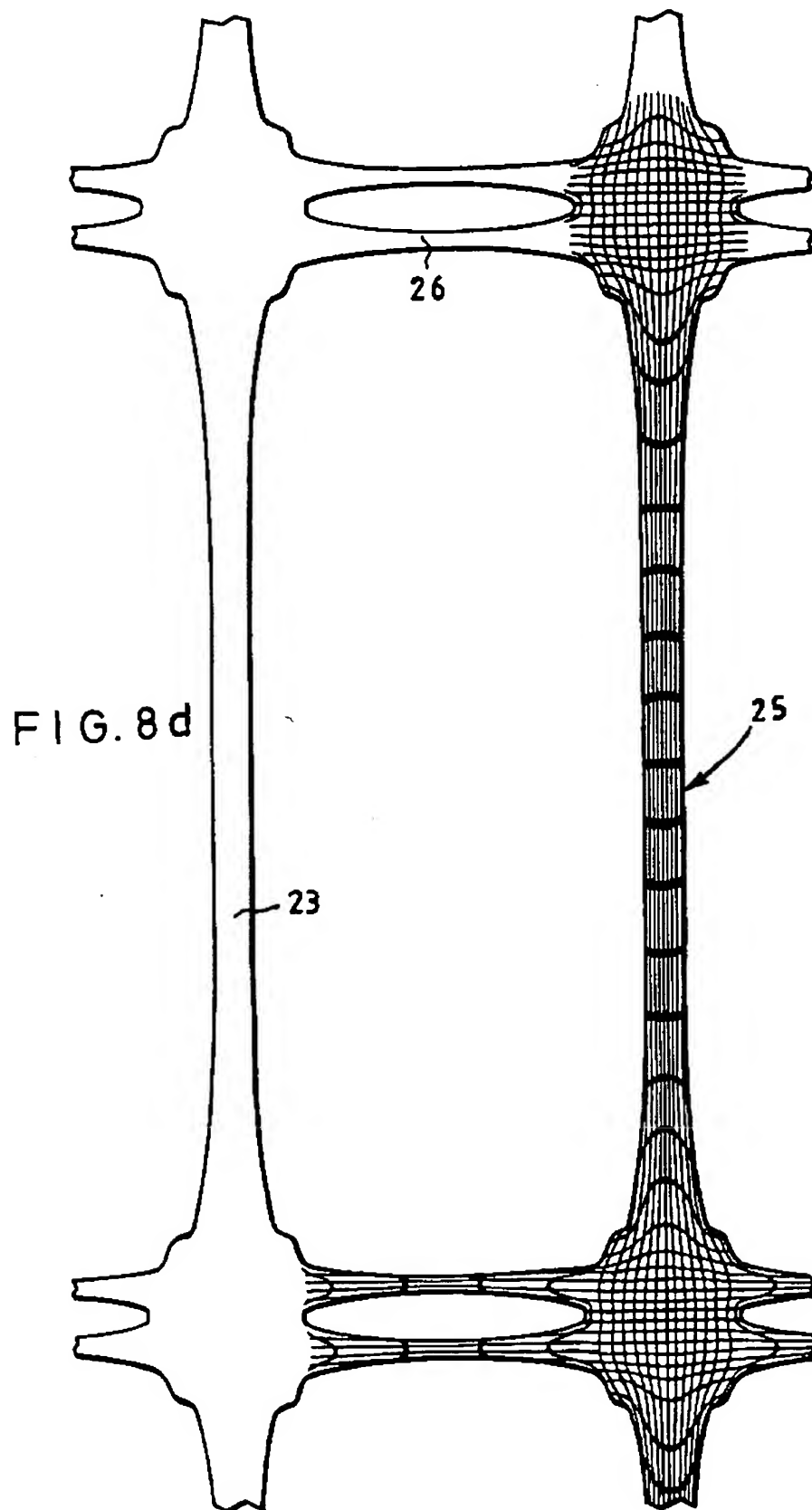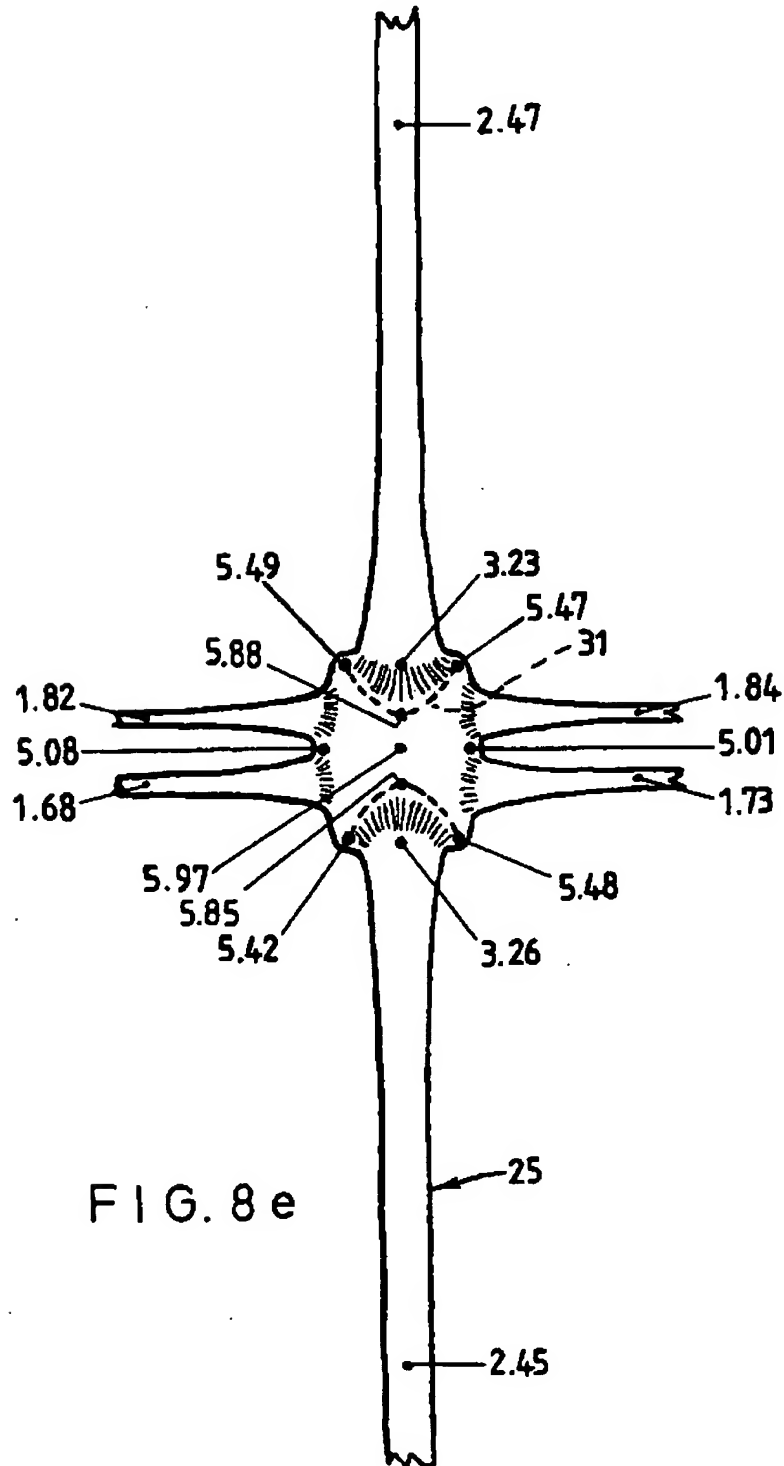
FIG. 8 e
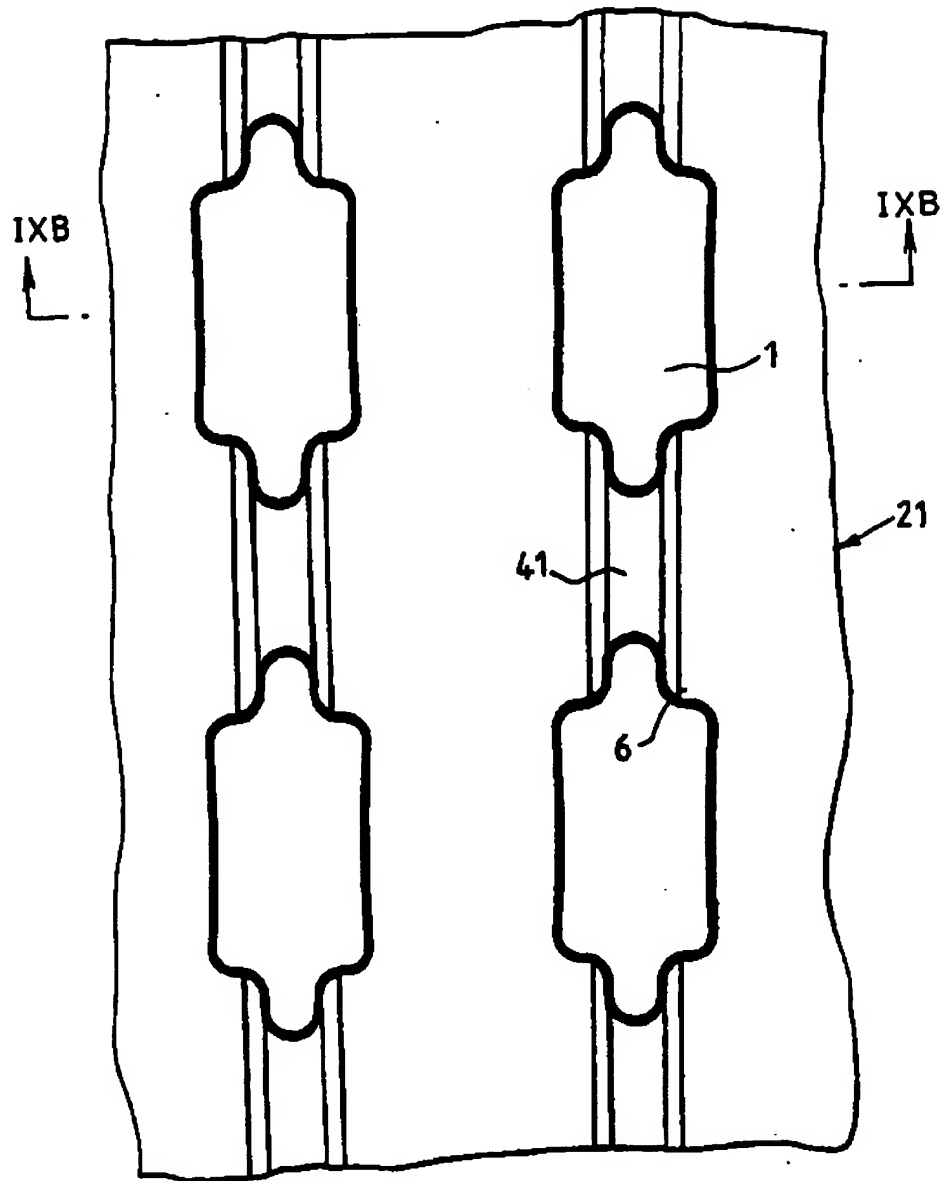
FIG.9a
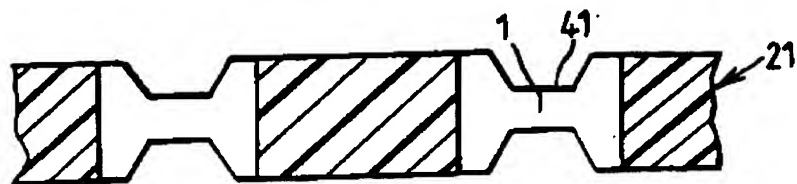
FIG.9b
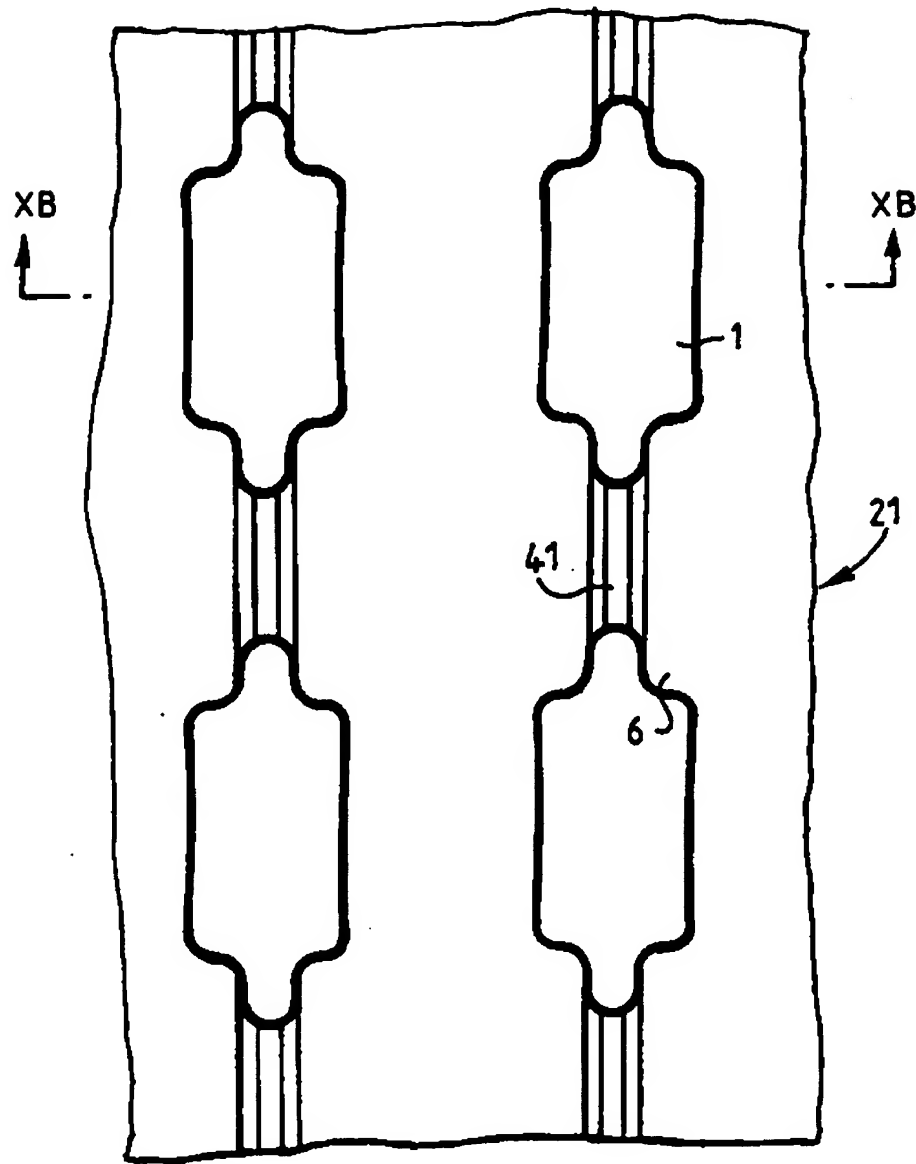
FIG.10a
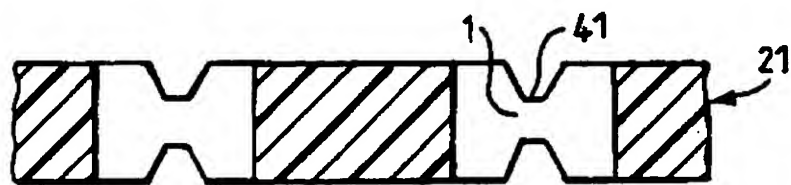
FIG.10b
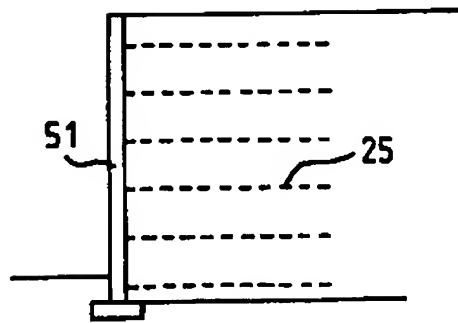
FIG.11
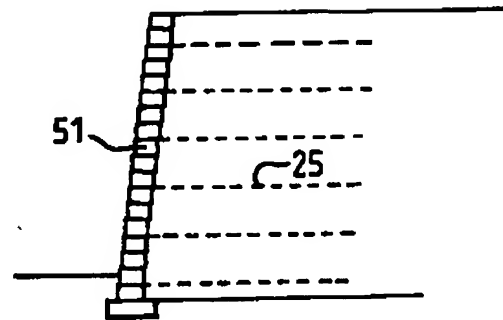
FIG.12
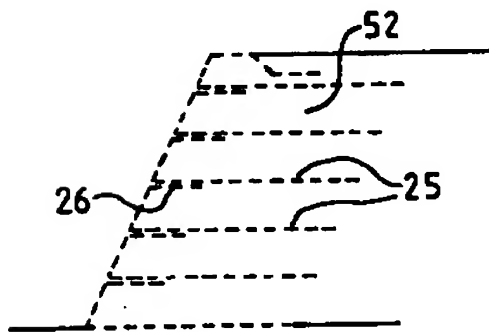
FIG.13
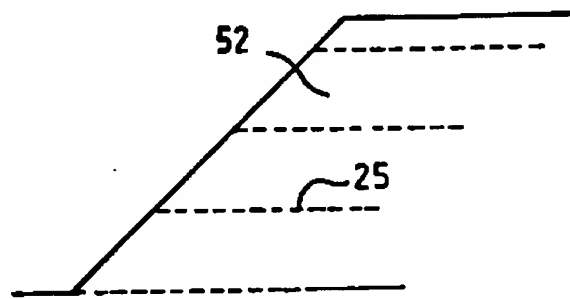
FIG.14
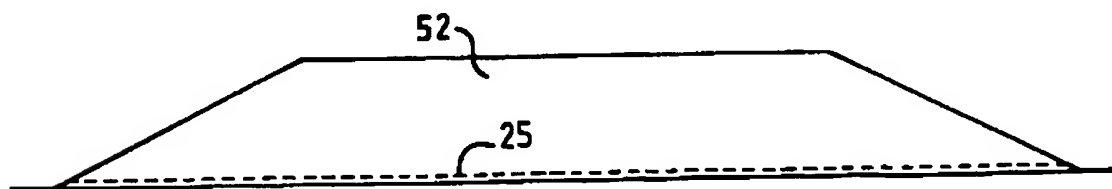
FIG.15

PLASTICS MATERIAL MESH STRUCTURES

Background of the Invention

The present invention relates to a method of producing a
biaxially-stretched plastics material mesh structure,
suitable for geotechnical and other civil engineering
uses; a mesh structure employed for such uses can be
referred to as a geogrid. The mesh structure is
unbalanced, ie has a greater strength in a primary
direction (PD) than in a secondary direction (SD)
substantially at right angles to the PD. The method
comprises providing a starting material which has a
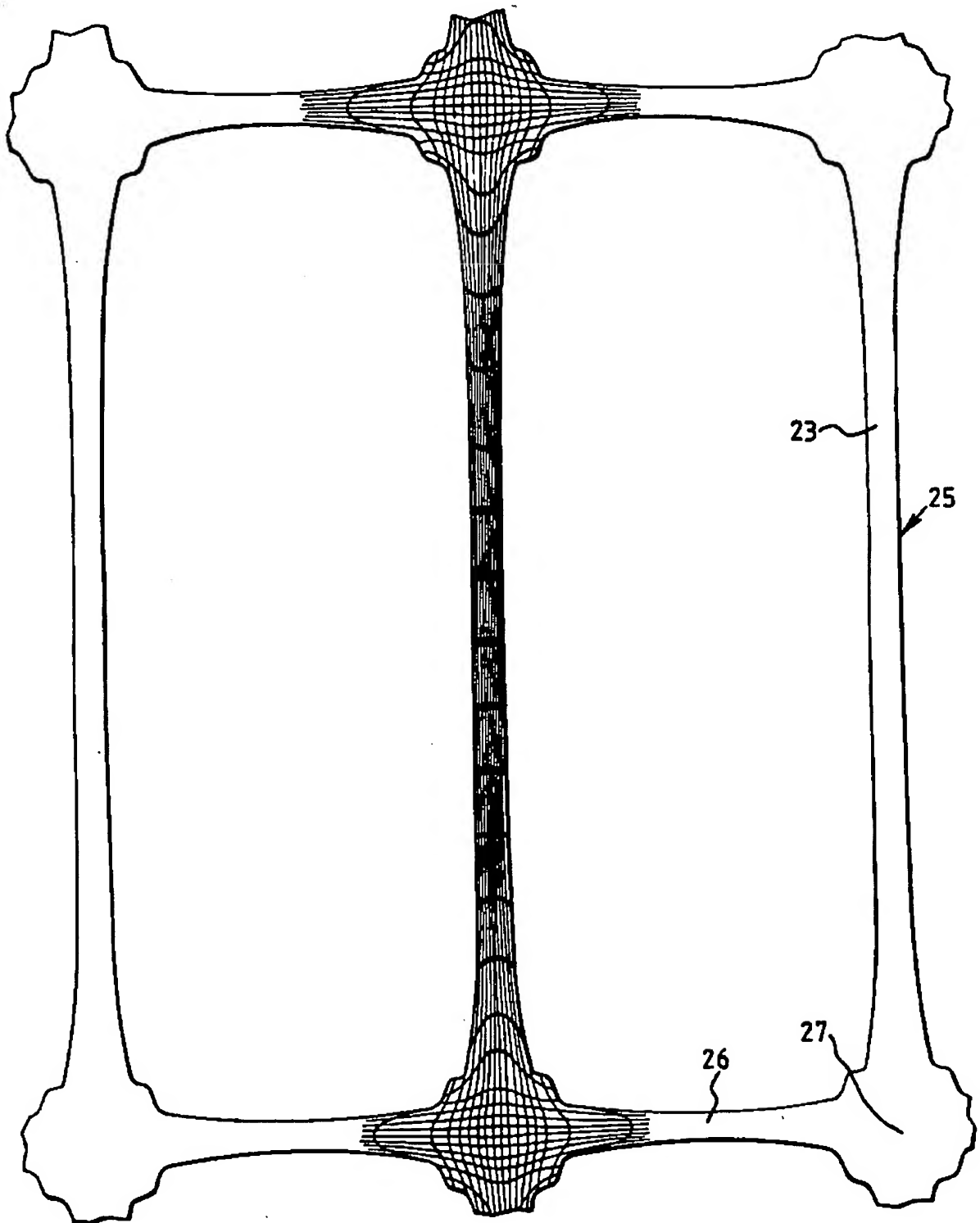thickness (defined below) of at least about 2 mm and has
a pattern of holes on a notional substantially square or
rectangular grid whose axes are substantially parallel
to the PD and to the SD respectively, the sides of PD
end portions of at least some of said holes being
defined by crotch-forming zones. The starting material
is of square construction; ie the PD and the SD are
aligned with the two orthogonal axes of the eventual
product. PD stretch is applied to form oriented PD
strands and to apply some orientation to the notional
junction zones (defined below) so that orientation
extends into and through the notional junction zones,
from the end of one oriented PD strand to the adjacent
end of the aligned oriented PD strand. SD stretch is
applied to form oriented SD strands. At least part of

the length of the edges of cr tches conn cting adj c nt
sides of adjacent PD and SD strands is riented in the
direction running round the crotch. The mid-point of
the notional junction zone (defined below) in the mesh
structure is significantly thicker than the mid-point of
any oriented strand entering the notional junction
zone.

The present invention also relates to a
biaxially-molecularly-oriented integral plastics
material mesh structure made from a starting material
which has a thickness of at least about 2 mm and
comprising oriented PD strands and oriented SD strands,
interconnected by junctions with respective sides of
adjacent oriented PD and oriented SD strands
interconnected by crotches at least part of whose length
is oriented with orientation running in the direction
around the crotch. The orientation of the PD strands
extends into and through the junctions. The junction
mid-point thickness is significantly greater than the
mid-point thickness of any oriented strand entering the
junction.

The mesh structures of the invention were designed for
applications in which the main tensile force will be
applied in the PD, and the mesh structures have
significantly greater strength in the PD than in the SD;
for instance, when the mesh structure is attached to a
vertical wall facing in a retained wall ge engineering

construction, the main t nsile forc will b at right angles to th facing and can be aligned with the PD of the mesh structure.

US 4 374 798 and US 5 053 264 disclose mesh structures of the general type with which the present invention is concerned. US 5 267 816 and US 5 269 631 disclose mesh structures which have greater strength in the PD than in the SD.

From the point of view of PD strength and failure mode, the best structure is found to be a uniaxially-oriented (uniax) structure, as for example strengths of up to at least 160 kN/m width can be achieved with a 5.5:1 PD stretch ratio. However, in order to reduce the time taken to build a geotechnical construction whilst maintaining the strength of the construction, it is desirable to increase the width of the geogrid without reducing the PD strength per strand or the economy rating in the PD more than about 5% or 10%. As there is a limitation on the width of starting materials, this can only be achieved in manufacture by stretching in the transverse direction (TD). Thus although the improvements of US 5 267 816 and US 5 269 631 are primarily directed towards significantly increasing the machine direction (MD) strength by enabling one to apply great r PD str tches, the present invention is more concerned with being able to apply SD stretches without

greatly r ducing the PD strength per strand or the economy rating, whilst providing a satisfactory creep strain behaviour with adequate long term strength. Nevertheless, it is very difficult to produce biax products whose PD strength per strand or economy rating is similar to the PD strength per strand or economy rating of the intermediate uniax material if reasonable stretches are applied in the SD. This is because the SD stretch affects the PD strength of the junction. Also the SD strands must be sufficiently robust eg to reinforce soil.

It is desirable to have a low SD punch-out in order to leave as much material as possible in the PD strand-forming zones and produce a high strength product using not too thick a starting material. However, if the SD punch-out is decreased, the PD orientation through the junction becomes more difficult to control.

It is desirable that any alteration in the manufacturing technique should produce a mesh structure which appears robust to the eye (as this is important for sales), and that the mesh structure should have an acceptable failure mode. As a general principle, it is desirable to have failure in the PD strand and not in the junction as this enables better prediction of the long term p rformance of the product.

Th Invention

According to the method of the invention, crotch-forming
zones in the starting material have protuberances. Each
protuberance may be in the plan view shape of the hole,
namely a portion of the crotch-forming zone which
projects into the respective hole beyond a base line
which is tangent to each end of the projecting portion.
Alternatively or in addition, the protuberance may be
out of the plane of the starting material, being a
thickening when approached from the edge of the PD
strand-forming zone and/or when approached from the edge
of the SD strand-forming zone. In the special case
where there is no thickening when approaching from the
edge of the PD strand-forming zone (defined below) and
also no protuberance as seen in the plan view shape of
the hole, there is a tendency for the orientation to
proceed too far around the crotch in the PD stretch.
This tendency is avoided by ceasing PD stetching before
the orienation has reached the thickening (which
considered as one progresses from the PD strand-forming
zone will be a decrease in thickness).

The size of said protuberance is such that during the
stretch, at least part of the edge of the crotch
interconnecting adjacent sides of adjacent oriented PD
and oriented SD strands is ori nted in th dir ction
running around the crotch, but the orientation ratio

ℓ

decreases significantly as one passes around the crotch
edge, either from the oriented PD strand or from the
oriented SD strand. In the biax product, the crotch
edge either a) has an unoriented part, or b) the
thickness of the least oriented part of the crotch edge
is reduced (or the length of the least oriented part of
the crotch edge is increased) by no more than about 20%
(or than about 15%, 10% or 5%, as alternatives) of its
thickness (or length) prior to stretching. The action
of stretching does not reduce the thickness of any point
along notional ridge lines of maximum thickness on the
product from the junction mid-point to the crotch edges
to such an extent that the ratio of finished thickness
to starting thickness at that point is less than about
80% (or than about 85%, 90%, 95%, as alternatives) of
the ratio of finished thickness to starting thickness of
the notional junction zone mid-point.

In the biaxially-stretched mesh structure of the
invention, the junctions comprise a central zone which
is thicker than thinner zones adjacent the ends of
oriented PD and oriented SD strands. If the junction
interconnects two oriented PD strands entering a
junction from opposite sides and two oriented SD strands
entering·the junction from two other opposite sides, the
junction central zone will be generally square or
rectangular; the central zone need only b generally
square or r ctangular and its sides could be concave or

convex.   The c ntral zone has a narrow projection at the corner extending outwards between said thinner zones, continuing through the crotch between the oriented PD strand and the oriented SD strand, and running into the crotch edge.   Though the central zone is thicker than said thinner zones, the narrow projection may be thicker than the central zone.   There is no point on a notional line of maximum thickness on the product from the junction mid-point to the crotch edge having a thickness of less than about 80% (or than about 85%, 90% or 95%, as alternatives) of the thickness of the junction mid-point.   The central part of the crotch edge zone can be convex.   The mesh material defined above is the product produced from a starting material with flat or nearly flat faces; if a starting material face or faces diverge markedly from flatness, the product will be altered correspondingly.

The invention extends to a method of strengthening soil, comprising embedding in the soil the mesh structure of the invention or the mesh structure produced by the method of the invention, and to a geotechnical construction (a composite civil engineering construction) comprising a mass of soil strengthened by embedding therein the mesh structure of the invention or the mesh structure produced by the method of the invention.

Definitions

The understanding of several of the following definitions is assisted by references in Figure 1a of the accompanying drawings, but the definitions are not limited to the shape of hole 1 shown in Figure 1a.

The term "oriented" means molecularly-oriented. In general, when an oriented strand is referred to, the preferred direction of orientation is longitudinal of the strand.

"Uniax" and "biax" mean uniaxially-oriented and biaxially-oriented, respectively. Substantially uniaxially-oriented means that on the surface of the structure, there has been extension of the material in one direction but no substantial resultant extension of the material in the direction at right angles.

In relation to a mesh structure, "biaxially-oriented" means that the mesh structure has been stretched in two directions generally at right angles to each other.

The "orientation ratio" is the stretch ratio in a localised area.

The holes in th starting mat rial may be through-holes or blind holes. If th holes are blind, the film or

membrane in the hol will either rupture on stretching, or may r main as a thin membrane.

A "tangent line" is a notional line tangent to the ends of the holes on either side of a strand-forming zone, whether or not the hole is in accordance with the invention. Figure 1a shows "SD tangent lines" 2 tangent to the PD ends of the holes 1 and "PD tangent lines" 3 tangent to the SD sides of the holes 1.

In extruded starting materials and in embossed or moulded starting materials, the holes are not normally vertical sided (ie perpendicular to the plane of the starting material). For extruded starting materials as a good approximation, the tangent line can be taken as the notional line tangent to the plan view see-through, ie the minimum hole size as viewed normal to the plane of the material, but ignoring film or feathered edges. For embossed or moulded starting materials, where the holes normally have sloping sides, as a good approximation, the tangent line can be taken as the notional line tangent to a point half way up the side of the hole, or, if the slope is different on each face, tangent to a point half-way between points half-way up the respective slopes, films or membranes in blind holes being ignored.

The "notional junction zone" 4 is the zone of the

starting material defined b tween the respectiv pairs of SD and PD tangent lin s 2, 3. In the mesh structures, the notional junction zones are the zones of the surfaces of the structure which have been formed from the notional junction zones of the starting material.

A "crotch-forming zone" 13 is the zone adjacent the corner of the respective notional junction zone 4, lying between a respective hole 1, the adjacent PD tangent line 3 and the adjacent SD tangent line 2.

A "PD strand-forming zone" 11 is the zone between respective holes 1 and at its ends between respective crotch-forming zones 13, which extends from the SD tangent line 2 tangent to the first PD ends of the respective holes 1 to the SD tangent line 2 tangent to the other, second PD ends of the holes 1.

An "SD strand-forming zone" 9 is the zone between respective holes 1 and between respective crotch-forming zones 13, which zone extends from the PD tangent line 3 tangent to the first SD ends of the respective holes 1 to the PD tangent line 3 tangent to the other, second ends of the holes 1. It is not necessary that orientation will pass along the whole of the SD strand-forming zone, and normally the very ends will not b stretched out.

"Strictly uniplanar" means that the material or structure is symmetrical about a m dian plane parallel to its faces. In general, a uniplanar starting material will give a uniplanar struture when stretched.

"Substantially uniplanar" means that the material or structure does not deviate so much from strict uniplanarity that orientation is not comparable on each face of the biax product.

A "strictly flat" starting material has monoplanar, parallel faces.

The "starting material" is the material immediately before initiation of the first stretch. However, when considering whether there is a thickening, the material should be as it would be without the application of the cold grooving technique described in US 4 590 029, if such a technique has been applied, as the technique has little effect on the final orientation behaviour.

"Punch-out" is the ratio of the maximum dimension of the holes (ie between the respective tangent lines) in a specified direction to the pitch of the holes in the same direction, whether or not the holes have been formed by punching or by another procedure which may not even involve material removal.

The terms "thick" and "thin" refer to the dimension

normal to th plane of the material or mesh structur . Unless otherwis specified, the thickness is the distance between the extreme faces at the thickest point. However, raised edges or tapered or feathered edges are ignored, as well as any minor grooves in the surface and any irrelevant projections from the surface.

The dimension "$\underline{t}$" is the mean thickness of the starting material where the dimension $\underline{a}$ is measured, ie at the minimum SD dimension (width) or narrowest part of the PD strand-forming zone 11, the part that often determines the strength of the product. $\underline{t}$ is taken as the "thickness of the starting material", whether or not other parts of the starting material are thicker.

Where a crotch edge is referred to, eg for measuring the thickness of the crotch edge, a point is taken as close to the crotch edge (as seen in plan view) as possible, whether or not the edge is raised or somewhat tapered, though ignoring any feathering or membranous material that does not form part of the crotch proper, ignoring abrupt tapering required for mould withdrawal in moulded starting materials, and ignoring any radiussing caused by punching holes, though the reduction in thickness leading up to the radiussing is not ignored; it has been found that the crotch edge zone can be reduced in thickness by 9% to 10% as a result of punching alone.

Th "width" is the dimension at right angles to the major axis of the z ne in question, and "narrow" relates to this dimension. "Narrow" means significantly longer than wide.

The stretch ratios are as measured after releasing the stretching force or after annealing if annealing is carried out, and as measured on the surface of the structure.

"HDPE" is high density polyethylene.

The "strength" of a mesh structure as used herein is the maximum strength per linear unit, measured in a normal tensile test, the linear units being in the direction at right angles to the direction in which the strength is measured, whether the strength is measured in the PD or in the SD.

The "rib strength" is the maximum strength per strand.

The "economy rating" is the PD strength of the product per unit width per mass per unit area, measured as kN per m per kg per m^2 in the PD.

"Truth lines" are parallel lines applied (normally by printing or drawing) to the starting material, normally in two dir ctions parallel to the PD and SD respectively.

The "shoulder tang nt" 5 is the tangent to a side of the projecting portion or pr tuberanc 6 at th point wh re the tangent makes the greatest angle with the PD, said angle being measured so that it is less than 90° if the shoulder tangent 5 is directed towards the PD centre-line 7 of the hole 1 and towards the centre-line 8 of the adjacent SD strand-forming zone 9 and so that it is more than 90° if the shoulder tangent 5 is directed towards the PD centre-line 7 of the hole 1 and away from the centre-line 8 of the adjacent SD strand-forming zone 9.

The "shoulder angle" is the angle θ which the shoulder tangent 5 makes with the PD.

The "neck tangent" 10 is the tangent to a side of the protuberance 6 at the point where the tangent makes the smallest angle (positive or negative) with the PD, said angle being measured so that it is positive if the neck tangent 10 is directed towards the centre-line 8 of the adjacent SD strand-forming zone 9 and towards the PD centre-line 7 of the hole 1 and so that it is negative if the neck tangent 10 is directed towards the centre-line 8 of the adjacent SD strand-forming zone 9 but generally away from the PD centre-line 7 of the hole 1.

The "neck angle" is the angle ψ which the neck tangent

10 makes with th PD.

The dimension "$\underline{a}$" is t.:3 minimum SD distance between adjacent side-by-side holes 1.

The dimension "$\underline{b}$" is the SD dimension between adjacent side-by-side holes 1, between the points where the respective neck tangents 10 are tangent to the sides of the protuberances 6 (measured at the point where the neck tangent 10 is coincident with the crotch edge and furthest from the PD end of the hole 1, if the respective part of the protuberance side is straight).

The dimension "$\underline{c}$" corresponds to the dimension $\underline{a}$, but is taken in the PD.

The dimension "$\underline{d}$" corresponds to the dimension $\underline{b}$, but is taken in the PD, between the points where the respective shoulder tangents 5 are tangent to the sides of the protuberances 6 (measured at the point where the shoulder tangent 5 is coincident with the crotch edge and furthest from the SD side of the hole 1, if the respective part of the protuberance side is straight).

The "junction diagonal ratio" is the ratio of the diagonal dimension in the biax product across two diagonally opposed points of minimum or zero orientation of crotches and across a junction, t the same diagonal

dimension i in the starting material.

The "base line" 12 of the protuberance 6 is the line tangent to each end of the protuberance 6.

The "projecting extent" j of the protuberance 6 is the greatest extent of the protuberance 6 as measured at right angles to the base line 12.

The term "soil" includes rocks, stones, gravel, sand, earth, clay, aggregate held by a binder such as asphalt, or any other particulate or cohesive material used in geotechnical engineering.

About the Invention

Using the invention, it has been found that the protuberance has made it possible to direct orientation positively through the junction, generally along the PD, while limiting the actual degree of orienation across the centre of the junction. The invention controls and limits the level of orientation in the crotches whilst nonetheless maintaining crotch edges which are oriented for at least part of their length in the direction running around the crotch. Although the crotches can be continuously oriented in the direction running around the crotch (ie "uniaxial" orientation), there are no crotches which are highly ori nted from nd to end.

Apart from the unoriented or low-oriented part of the crotch edge, there is a range of orientation ratio in the crotch edge extending continuously from the ratio in the unoriented or low-oriented part up to the orientation ratio of the respective oriented strand, or to a value even greater than that in the oriented strand. When PD stretch is applied, the protuberance provides a rapid increase in the cross-sectional area of the crotch-forming zone as the orientation progresses from the yield point(s) in a PD strand-forming zone towards the junction; the rapid increase is preferably followed by a region of more slowly increasing cross-sectional area. In other words the invention puts a block in the centre part of the crotch-forming zone, thereby preventing in a controllable manner high orientation passing all the way around the crotch edge. The invention also controls and limits any orientation passing behind the block, both in the PD stretch and in the SD stretch. The block is characterised in the product by a sharp increase in thickness (called a neck) in the crotch as one goes around the crotch from the side of the respective PD strand. For instance, one can obtain a very low crotch edge thickness reduction, of less than about 20% or even of less than about 5%, at the crotch-edge centre portion. As there will often be a sharp increase in thickness on either side of the unoriented or least oriented part of the crotch edge as this part is approached, the crotch edge thickness

should be measured at its thickest point, or its extension should be measured at its part of least extension; thus, if it is difficult to measure the reduction in thickness of a crotch edge, its extension (ie orientation ratio) can be measured, for instance by drawing parallel lines across the median plane on the side face of the starting material (which parallel lines are as close together as practicable), and measuring their separation on the starting material and on the product (after biaxial stretching). The region having the increase in thickness can have a slope of about 45° to the plane of the mesh structure, ie an included angle of about 90°.

The effect of the invention occurs even if the PD strand-forming zones form a large part of the SD width of the starting material, and the invention can be used with low SD punch-out ratios; thus the SD punch-out can be less than about 60%, 55% or 50%, and preferably less than about 46%. This enables the economic manufacture of high PD strength products from relatively low thickness starting materials.

The invention eliminates or greatly reduces any tendency to splitting of transverse strands when the mesh structure is subject to PD forces. In other biax products, this can occur as a result of force transmission around highly oriented crotches to the

adjacent SD strands; such splitting causes failure of the m sh structure in the junction zones and prevents the strength of the oriented PD strands being fully mobilised. In other words, in the structures of the invention, the junction stress pattern is more efficient when the structure is subjected to PD forces, and the structure can have a behaviour similar to that of a uniax structure. The PD and SD stretches do not interact or do not interact greatly, enabling the strength of a junction and hence the economy rating of a uniax structure to be maintained to a large extent in the final biax structure; thus it is preferred that during the SD stretch the mid-point of the junction does not reduce in thickness so that the orientation of the junction mid-point is uniaxial in the PD, though this is not essential. It is not necessary that all the SD strand-forming zone be stretched out on the SD stretch. The narrower very end portions of the hole (considered in the PD) can provide a narrow yield point for SD orientation and provide small bar widths (PD dimension) in a convenient manner; with suitable choice of PD pitches, the penetration of transverse orientation into the junction during the SD stretch is reduced whilst leaving enough material to form a satisfactory junction. There are no thin zones in the junctions such as could form tear starters and weaken the structure und r the action of tensile forces.

An unexpect d advantage of th invention is that th
product can be very regular, even when produced using
low (slow) strain-hardening materials, ie materials with
a high natural draw ratio.

It has been found that a 4 m wide biax mesh structure
which appears regular and robust to the eye can be
formed from a starting material of about 1.5 m in width
of a thickness not greater than 6.5 mm with a strength
per metre width of 40 kN/m, having an acceptable failure
mode and a satisfactory creep strain behaviour with
adequate long term strength. Using the invention, it is
possible to achieve resultant stretch ratios of up to
18:1 or more, for instance 5.5:1 in the PD and 3.3:1 in
the SD. The PD stretch ratio (as measured from the
mid-point of one notional junction zone to the mid-point
of the adjacent junction zone in the PD) is preferably
at least about 3:1 and more preferably at least 4.5:1 or
5:1. For higher strength products from a given starting
material thickness, lower SD stretch ratios may be used,
down to 1.5:1. The PD strength is significantly greater
than the SD strength, eg at least about 1.5, 2, 2.5 or 3
times the SD strength. 6.5 mm sheet is sufficiently
thin to be handled in production without particular
difficulties though as machinery develops in the future
it is anticipated that thicker materials, eg up to 15
mm, may be readily handled. In one xample with about
8% crotch dge thickest part thickn ss reduction, the

short term tensile behaviour of the biax product was found to be similar to that of the uniax interm diate product but the creep behaviour was found to be slightly worse than that of the uniax intermediate product.

As the orientation goes right through the junction in the PD stretch, the mid-point of the notional junction zone thins down, preferably by not more than about 10% and if possible by not more than about 5%. Due to pulling plastics material from other parts of the structure or due to relaxation of some of the orientation inserted during the PD stretching, the junction mid-point could increase in thickness during the SD stretch. Thus the final junction mid-point thickness is measured rather than the uniax thickness. The junction mid-point thickness will be significantly greater than the strand mid-point thicknesses, say at least twice the thickness, ie a difference in thickness which is not just due to random variation and which indicates that there is much greater orientation in the strand than across the junction. If desired, there can be continuous, substantially uniaxial orientation from end-to-end of the mesh structure, which provides reasonable long-term creep resistance, though this is not essential. In situations where long-term creep resistance is of less significance, one may use mesh structures of the present invention whose cr ep performance is inferior to that of a good

custom-designed uniax mesh structure.

It is preferred that the junction diagonal ratio be
close to unity, for example greater than about 0.8.   If
the ratio is unity, the diagonals of the junction have
not altered in length during stretching, but usually the
diagonals become shorter due to narrowing of the ends of
the strand-forming zones and the junctions caused by
stretching.

In general terms, the crotch-forming zone as seen in
plan view as one progresses towards the PD end of the
hole, can have:

    i)   a first part which widens out;

    ii)   a second part which does not widen out as
        rapidly as the first part;

    iii)   a third part which widens out more rapidly
    than the second part and terminates the
    crotch-forming zone.

Said first part is preferably immediately contiguous to
the second part.   Said second part is preferably
immediately contiguous to said third part.

More specifically, the shape can be such that as one
progresses towards the PD end of the hole:

    iv)   the sid of said first part is progr ssively
    more inclined to the PD axis and is defined at least

in part by a curve which is concav with resp ct to
the hole;

v)   the side of said second part is progressively
less inclined to the PD (the angle of inclination
can reduce to zero and then increase in the opposite
sense) and is defined at least in part by a curve
which is convex with respect to the hole; and

vi)   the side of said third part is progressively
more inclined to the PD and is defined at least in
part by a curve which is concave with respect to the
hole.

The b: a ratio is preferably greater than about 1. 5: 1 or
about 1. 6: 1, a specific preferred minimum value being
about 1. 64: 1.   The higher the b: a ratio, the greater the
protection of the crotch and the less the orientation
around the crotch.   The maximum value of the b: a ratio
is believed dictated by economical considerations (too
much punch-out and lower strengths per metre width)
rather than functional considerations and may be up to
about 2. 5: 1 or up to about 3: 1 or greater.

Consideration of the b: a ratio is relevant to starting
materials where there are protuberances in the
crotch-forming zones as seen in plan view and primarily
where there is no change in thickness in the
crotch-forming zone.   Howev r, the b: a ratio can be
expressed as a ratio of the cross-sectional areas in th

planes corresponding to those containing b and a. The
cross-sectional ar a ratios are applicable to starting
materials where there is a change in thickness or both a
protuberance in plan view and a change in thickness.
The planes would be those immediately before the change
in thickness and immediately after the change in
thickness. In general terms, one can consider the rate
of increase in SD cross-sectional area over a certain PD
distance.

At least up to 90°, the greater the shoulder angle θ,
the greater the protection of the crotch and the less
orientation around the crotch. Any inflection or
protuberance enables a satisfactory product to be
manufactured at reduced SD punch-out, and it is believed
that the closer the protuberance is to having
right-angled shoulders, the lower the SD punch-out that
may be used if a certain mode of failure is preserved.
The angle θ is preferably more than about 50°, 60°,
65°, 70° or 75°; the angle θ is preferably less than
about 135°, 125°, 115°, 110° or 105°; the preferred
angle θ is about 90°.

The angle χ between the shoulder tangent 5 and the
neck tangent 10 is preferably roughly 90° or an obtuse
angle. The neck angle ψ is preferably about 0°.
However, it is not excluded that the neck angle should
have a negative value, ie with the hole 1 widening out

again from a narrower "neck" as one approaches the PD end of the hole 1.

Considered in the SD, the crotch-forming zones can be as (i) to (iii) or (iv) to (vi) as set out above in relation to the crotch-forming zones as considered in the PD. The $\underline{d}$: $\underline{c}$ ratio determines at least in part the amount the junction and crotch centre are thinned and oriented in the SD stretch. The $\underline{d}$: $\underline{c}$ ratio is preferably greater than about 1.5:1 or greater than about 2:1; the ratio is preferably less than about 3:1 or less than about 4:1. By having the $\underline{d}$: $\underline{c}$ ratio sufficiently large, any reduction of the thickness of the centre of the junction during the SD stretch can be avoided. In order to prevent the SD orientation penetrating too far towards the mid-point of the junction, the width $\underline{c}$ of the SD strand-forming zone 9 can be reduced or the bar thickness can be reduced, for instance by extruding material with PD grooves registering with the centre parts of the holes or for instance using the technique described in US 4 590 029. The SD orientation can be taken beyond the line on which the dimension $\underline{d}$ is measured. It is preferred that during the SD stretch, the orientation does not extend so far around the crotch that the whole of the crotch is oriented.

The base line 12 of the protuberance 6 preferably makes an angle ϕ with the PD of more than about 30° or 35°;

the angle ϕ is preferably less than about 60° or 55°.
The proj cting extent j can be about 3% to about 15%,
preferably about 5% to about 10%, of the length of the
diagonal i. If the base line 12 of the protuberance 6
is too short and if the projecting extent j is too
great, there will be a tendency for the orientation to
go behind the protuberance 6 as though the protuberance
6 were not there.

Preferably, the very LD ends of the holes 1 will be
formed by continuous curves, though this is not
necessarily so as the ends could be formed by straight
SD lines. The sides of the crotch-forming zones 13 will
be formed by curves (which are not necessarily circular
arcs) which can connect directly into one another or can
be connected with one another by straight lines; the
connections are smooth, ie no very small radius kinks or
notches, at least where there is a connection that is
concave to the hole 1. The radii should not be so small
as to cause a notch and not so large as to impair the
blocking function of the protuberance. The radii chosen
can have a significant effect on the formation of the
block.

Normally, it is preferred that each hole 1 be
symmetrical about the PD axis and/or about the SD axis.
The central parts of the sid s of th PD strand-forming
zones, ie th parts connecting said PD nd portions, can

b any suitabl shape, g of "diabolo" shape as disclosed in US 4 743 486, straight, or elliptical concave with respect to the hole 1. Grooving techniques such as the cold grooving described in US 4 590 029 can be applied to the PD or SD strand-forming zones 11, 9.

The area of the PD strand-forming zone, as seen in SD section normal to the mesh structure between the respective PD tangent lines, is preferably less than about twice the area of the SD strand-forming zone as seen in section normal to the mesh structure and along the axis of the centre line of the SD strand-forming zone from the PD tangent line at one end of the zone to the PD tangent line at the other end of the zone. On a flat sheet, this ratio is equivalent to the SD punch-out.

Complex Starting Material Hole Configurations

The invention is applicable to more complex starting materials of square construction where some of the holes are different and are not on the same notional square or rectangle grid as the shaped holes of the inventions, eg as described in US 4 536 429 or US 4 574 100. However, in general, the invention is either applied to substantially every junction, or, with said more complex starting materials (where there will be junctions of diff rent typ s in the biax products), the invention is applied to substantially every junction of a certain

type.

Depending upon the configuration of the holes in the
starting material, a plurality of junctions could be
connected together not by oriented strands but by
unoriented or low-oriented material. In this manner,
there can be a plurality of junctions connected in the
PD and/or in the SD, the so-connected junctions
interconnecting six or more oriented strands. The
junction mid-point continues to be that point that
corresponds to the mid-point of the notional junction
zone, taking all holes into account unless they do not
contribute to the formation of an oriented strand. Thus
the invention is applicable to just one corner of a
junction; each crotch which interconnects an oriented PD
strand and an oriented SD strand can be of the form of
the invention with the other crotches being of other
forms. With such a mixed starting material, the
dimensions a and b or c and d can be measured to the
centre line of the respective PD or SD strand-forming
zone.

In one form of starting material that provides such
connected junctions, there are holes in accordance with
the invention aligned in the PD; in the SD, holes in
accordance with the invention are interspersed between
other hol s which are not in accordance with the
invention, eg holes as disclos d in US 4 743 486. In

the SD, there can be one said other hol b tween holes
in accordance with the invention, or, if less SD
extension is required, two, three or any suitable number
of said other holes. The PD distance between said other
holes may need to be greater than the PD distance
between the holes in accordance with the invention. The
holes are such that during the SD stretch, only the SD
strand-forming zones between the holes in accordance
with the invention stretch out. It is found that such a
structure has better long-term creep performance, though
its SD dimension will not be maximised, overall SD
stretch ratios being reduced to say about 1.5:1 or less.

In another form of the invention, holes of the invention
are interspersed in the PD between other holes which are
not in accordance with the invention, the SD width of
the latter other holes may need to be less than that of
the holes of the invention, ie in the PD, there may be
wider holes (greater SD dimension) interspersed with
narrower holes. The narrower holes between the holes of
the invention can assist in producing the crotch block
effect of the invention. On stretching in the PD, the
narrow gaps between the PD ends of the wider and
narrower holes prevent the crotch being stretched right
out and assist in the formation of a block; on
stretching in the SD, the narrow gaps act as narrow
yi ld points and assist in preventing larg forces being
applied across the junction.

In another form of starting material, the invention is applied to one side of the hol but not to the other side of the hole, giving a hole which is asymmetrical about its PD axis.

There may be other ways of achieving the crotch block effect.

There is available a mesh structure in which the SD oriented strands are each wholly or partially divided into two generally superimposed strands which may be somewhat displaced relative to each other in the PD, looking at the structure in plan, formed from an extruded starting material in which a slot is formed in the PD through the middle of the SD strand-forming zone. The present invention could be applied to such a starting material. Structures produced in this manner are expected to have the advantages of the invention.

Starting materials

The starting materials can be in general as set out from column 10, lines 20 to 24 and from column 10, line 32 to column 11, line 6 of US 5 269 631, which disclosure is incorporated herein by reference. The preferred plastics materials are polyolefins. The experimental work on which th pr s nt inv ntion is based was performed on medium molecular weight HDPE, which has a

relatively low rate of work hardening. Other material, and also factors such as differ nt stretching temperatures and rates and different degrees of restraint at right angles to the stretching direction, can significantly change the mesh structure produced. Thus, test pieces of the starting material should be stretched on a laboratory scale to determine whether they perform in accordance with the invention.

The holes 1 can be made in any suitable way; the preferred way is to punch, though moulding is possible and in theory a Hureau-type or Rical-type or Sire-type die head (as in FR 2 131 842 or US 3 252 181) could be used if the hole shape and thickness profiles can be sufficiently well defined. The starting materials need not be strictly or even substantially flat and can be for instance as disclosed in US 5 053 264 or the bumpy materials which may be formed by extrusion with the Hureau-type or Rical-type or Sire-type die head. Normally, a moulding process and a Hureau-type or Rical-type or Sire-type die head provide holes with tapered sides. The starting materials need not be substantially uniplanar though are preferably so. The starting materials may be grooved as described above or may be specifically profiled, eg as described in US 5 267 816. The starting materials are preferably not substantially oriented, though melt flow ori ntation can be present.

Testing

As the behaviour of the starting material varies with
many factors such as the resin used, the thickness, the
stretching temperature, the hole shapes and the hole
pitches, laboratory samples should be produced and
tested before carrying out tests on a production line,
to ascertain whether the desired orientation behaviour
is achieved. The application of truth lines to a
laboratory sample greatly assists in observing the
orientation behaviour.

Production Plant

Though not essential, the PD stretch will normally
precede the SD stretch. In production, the PD will
often be the machine direction (MD), but it could be the
transverse direction (TD). Although it is normally more
economical to carry out sequential MD/TD stretching with
the TD stretch following the MD stretch, it is not
essential for the present invention that the TD stretch
should follow the MD stretch. Thus the PD stretch can
be carried out before or after the SD stretch.
Furthermore, multi-stage stetching can be employed,
particularly in the PD; in such a case, the PD
orientation need not be taken right through the junction
until the final PD str tch. In normal manufacturing
practice, the mesh structure is formed as a long MD

length which is rolled up. It is not necessary to cool betw n stretches, and all or any two or any three stretching operations can be carried out in-line without cooling.

The plant illustrated in Figure 11 or 11a̲ of US 4 374 798 can be used in commercial production to carry out the stretching operations of the inventions in two stages; alternatively the stretching may be in three or more stages, eg as described in US 5 269 631.

Uses

The principal use is for strengthening soil and making a geotechnical structure, as referred to above, when the biaxially-stretched structure would be referred to as a geogrid. The uses set out from column 17, lines 45 to 61 and from column 17, line 64 to column 18, line 59 of US 5 269 631 are appropriate for the mesh structures of the present invention. The mesh structures of the present invention are particularly suitable for retaining walls or embankments, with the PD generally at right angles to the face of the wall or embankment as seen from above. However, the mesh structures can be used for other purposes. For instance, the mesh structures can be used in asphalt road constructions, particularly to avoid reflective cracking, or can be used in concrete constructions in order to control

shrinkage cracking.

Preferred Embodiments

The invention will be further described, by way of
example with reference to the accompanying drawings, in
which:

Figure 1a is a diagram of four holes in a first starting
material for making a geogrid;

Figure 1b is a plan view of the same starting material
as in Figure 1a, but showing truth lines;

Figure 1c is a plan view of the uniax intermediate
material made from the starting material of Figure 1b;

Figure 1d is a plan view of the intermediate material of
Figure 1c, showing the thicknesses;

Figure 1e is a plan view of the biax product made from
the starting material of Figure 1b;

Figure 1f is a plan view of one of the junctions shown
in Figure 1e, showing the thicknesses;

Figure 1g shows the dimensions of the holes in the
starting material of Figure 1a;

Figures 2 to 6 show the dim nsions of holes of second to
sixth starting materials;

Figures 7a to 7e correspond to Figures 1b, 1c and 1d to
1f but using a seventh starting material, the holes
being as in Figures 1g and 7f;

Figures 8a to 8e correspond to Figures 1a to 1e but
using an eighth starting material, the larger holes
being as in Figure 1g and the smaller holes being 4. 763
mm long with 1. 588 mm radius semi-circles at each end;

Figure 9a is a plan view of a first grooved starting
material;

Figure 9b is a section along the line IXB-IXB in
Figure 9a;

Figures 10a and 10b correspond to Figures 9a and 9b, and
show a second grooved starting material; and

Figures 11 to 15 are vertical sections through different
geotechnical constructions incorporating the mesh
structure of the invention.

The truth lines shown in the Figures can be
screen-printed on the starting material, and indicate
the progress of orientation, at least on the surfac of

e

the structur . They would not normally be provided on commercial materials.

The contour hatching in the Figures indicates a steep slope (increase in thickness), the hatching lines extending up the slope.

When more than one like junction of a stretched material is shown, all junctions are shown as identical although in production there could be small differences between junctions. In Figures which show successive stages, the junctions are not necessarily the same junction and the truth lines may be in somewhat different positions as it was necessary to use different test pieces.

In the Figures all dimensions are given in millimetres; where thicknesses are given, they are the thicknesses at the points indicated. A dimension with a single arrow indicates a circular arc. All arcs are circular arcs.

Figure 1a

Figure 1a shows various items defined above. Figure 1a also shows crotch-forming zones 13 adjacent the corners of the notional junction zones 4, each lying between a respective hole 1, the adjacent PD tangent line 3 and th adjacent SD tangent line 2, one such zone 13 being shown cross-hatched in. If the holes 1 terminate in a

rectilinear portion extending in th SD, the
crotch-forming zones 13 will not define the very PD ends
of the holes 1. In Figure 1a, each PD strand-forming
zone 11 can be considered as a zone between respective
holes 1 and at its ends between respective
crotch-forming zones 13, which extends from the SD
tangent line 2 tangent to the first PD ends of the
respective holes 1 to the SD tangent line 2 tangent to
the other, second PD ends of the holes 1, one such zone
11 being shown cross-hatched. In Figure 1a, each SD
strand-forming zone 9 can be considered as the zone
between respective holes 1 and between respective
crotch-forming zones 13, which extends from the PD
tangent line 3 tangent to the first SD ends of the
respective holes 1 to the PD tangent line 3 tangent to
the other, second SD ends of the holes 1, one such zone
9 being shown cross-hatched.

Figures 1e to 1f

The starting material 21 in Figure 1b has been punched
from strictly flat sheet. The hole 1 shape and
dimensions are as shown in Figures 1a and 1g. The hole
1 is of waisted shape, in accordance with US 4 743 486.
The thickness can be 6 mm, and details can be as in
Example 1 of the Table below. In the manner indicated
with reference to Figure 1a, the crotch-forming zones 13
hav protuberances 6 with features (i) to (vi) r f rred

to above.   Th yi ld points of the PD strand-forming zones 11 are at their narrowest parts (where the dimension $\underline{a}$ is shown in Figure 1$\underline{a}$).

Figures 1$\underline{c}$ and 1$\underline{d}$ show the uniax intermediate material 22, after the application of PD stretch.   The PD strand-forming zones 11 have been stretched out into highly oriented PD strands 23 interconnected by transverse bars 24.   As can be seen from slight splaying of the SD truth lines, a small amount of PD orientation has been taken right through the notional junction zones 4 and there is continuous uniaxial orientation extending from end to end of the structure.

From the thickness chart of Figure 1$\underline{d}$, it can be seen that the PD orientation in the PD strands 23 has extended round the crotches, but the size of the protuberances 6 is such that they have acted as a block and the orientation ratio decreases significantly as the orientation approaches the central part of the crotch edge, although the decrease may differ slightly from crotch to crotch.   For each crotch, the orientation ceases just beyond the centre of the crotch edge.

Figures 1$\underline{e}$ and 1$\underline{f}$ show the biax product or geogrid 25 after the application of SD stretch.   The SD stretch is such that the SD orientation ceases just b fore the crotch edge centres, thereby providing continuous

orientation around the crotches from nd to end in the
direction of the crotches, but with low orientation in
the crotch edge centres, the crotch edge centre
thickness reductions noted in the uniax intermediate
material 22 remaining substantially the same.   The
maximum thickness of the thickest part of the crotch
edge does not coincide with the centre of the
protruberance 6, and is more than about 80% of the
thickness of the mid-point of the biax junction 27.   The
SD orientation is not taken across the centre of the
notional junction zone 4, ie there is no further
reduction in thickness of the centre of the notional
junction zone 4, and the junction mid-point remains
uniaxially oriented; the SD orientation ends at about
1.5 mm from the junction mid-point.   Figure 1f is
somewhat anomalous because some of the thicknesses are
greater than in Figure 1d, due to using different
samples.   The central portions of the SD strand-forming
zones 9 have been stretched out into highly oriented SD
strands 26.   The junction 27 comprises a generally
rectangular central zone 28 which has a slight dip
running through its middle in the PD.   The central zone
28 is however thicker than zones 29 on all four sides of
the central zone 28; the zones 29 on the SD sides and/or
PD sides may not be in the notional junction zone.
There are narrow projections 30 at the corners of the
central zone 28, extending outwards, continuing through
the crotches, and running into th crotch dges.   The

c ntral parts of th crotch edg s are convex relative to
the junction. Figure 1f indicates with dashed lines 31
the notional lines (ridge lines) of maximum thickness
from the mid-point of the junction 27 to the crotch edge.

The PD strands 23 are closer together than the SD
strands 26, although they need not be so, and have a
greater cross-sectional area than the SD strands 26,
although they need not have, but one of these features
should be present so that the biax product 25 has
significantly greater strength in the PD than in the SD.

Figures 2 to 6

These Figures show the shape and dimensions of the holes
1 for the second to sixth starting materials. The holes
1 shown in Figures 2, 4, 5 and 6 are of waisted shape,
in accordance with US 4 743 486. The hole shape shown
in Figure 4 is the same as that of Figure 1g, except
that the end portions have a zone with parallel sides
and the very end radius is relatively large.

Figures 7a to 7f

These Figures will not be described in detail. In the
starting material main holes 1 in accordance with the
invention are interspersed in the SD between other,
subsidiary holes 32 which are not in accordance with the

invention and are shorter in th PD than in the main holes 1. In the PD stretch, all the PD strand-forming zones stretch out. In the SD stretch, the wide SD strand-forming zones between the holes 32 do not stretch out and remain unoriented or only slightly oriented. In the biax product, pairs of junctions (notional junction zones) are connected in the SD by a zone of low-oriented material as shown in Figure 7e. However, for the left and right hand crotches of the junction pairs, the orientation behaviour is generally as in Figures 1e and 1f. The top and bottom middle crotches of the junction pair are not oriented. The mid-points of the notional junction zones are indicated by the thicknesses 5.83 and 5.85 in Figure 7e. The ridge lines 31 are taken from these mid-points, and are shown running into the left and right hand crotches of the junction pair. In the biax product 25, the PD strands 23 are in groups of two.

Figures 8a to 8e

These Figures will not be described in detail. In the starting material, main holes 1 in accordance with the invention are interspersed in the PD between other, subsidiary holes 33 which are not in accordance with the invention and are narrower than the holes 1. In the PD stretch, the PD strand-forming zones between the holes 1 stretch out but th wider zones betwe n the holes 33 do not stretch out significantly; some minor contraction

occurs in th SD. In the SD stretch, all the SD
strand-forming zones stretch out. In the biax product,
pairs of junctions (notional junction zones) are
connected in the PD by a zone of low-oriented material
whose mid-point is indicated by the thickness 5.97 in
Figure 8e and is biaxially oriented. However, for the
top and bottom crotches of the junction pair, the
orientation behaviour is generally as in Figures 1e and
1f, although there is some biaxial orientation in the
centres of the notional junction zones. The crotches in
the middle of the sides of the junction pair are
unoriented or only slightly oriented. Ridge lines 31
are shown running from the notional junction zone
mid-points into the top and bottom crotches of the
junction pair.

Figures 9a and 9b

Figures 9a and 9b show a first starting material 21
which has deep PD grooves 41 with tapered sides passing
through the centres of the holes 1. It is believed that
different dimensional parameters, including the b:a and
d:c ratios will apply for such starting materials than
the parameters described herein for flat starting
materials. In Figure 9a, as one progresses from the PD
strand-forming zone around the crotch edge, there is
initially no decr ase in thickness and th n a rapid
decrease in thickness at the site of the protuberance

R

6. Th grooves 41 provid good yield points for th SD stretch and the rapid increase in thickness as one progresses along the SD strand-forming zone prevents excessive penetration of the SD orientation into the junction. In the product, the thickest part of the crotch edge is at a position corresponding to a position on the starting material just before the rapid decrease in thickness.

Figures 10a and 10b

Figures 10a and 10b correspond closely to Figures 9a and 9b, except that the grooves 29 are narrower.

Examples

A number of laboratory samples were prepared using flat HDPE sheet of about 0.95 g/cc density and nominal thickness 6.0 mm. The sheet of Example 2 was made from a Soltex resin produced by Solvay; the sheet for the other Examples was made from a resin produced by Borealis. The latter resin is slightly poorer when the biax products are compared but was available for large scale manufacture. Both resins were medium strain-hardening material. Sheets were punched and screen printed with a 1.6 mm square grid pattern. The sheets wer stretch d at a t mperature of 105°C in two directions at right angles at a r lative cross-head

speed of 250 mm/min, being stretched s quentially first in th PD and then in the SD. Th samples were effectively unrestrained in the SD during the PD stretch; the samples were all restrained in the PD during the SD stretch to simulate manufacture in a plant with PD stretching first in the MD, the restraint being close to 100%. The stretch ratios are overall (after any contraction that may occur after releasing the stretching force). Test specimens were cut from the samples, each comprising a single strand with three junctions except for Example 6 where the specimens comprised pairs of PD strands. For tensile testing, each specimen was gripped by jaws at the two extreme junctions, the middle junction being centrally disposed. Tensile loads were applied axially (PD or SD) to the specimen at a cross-head displacement rate of 50 mm/min. All testing was at 20'C ± 1'C.

Examples and test results are given in the following Table. "n/a" indicates that the relevant measurement test or calculation was not carried out. In Example 7, the SD punch-out is given for the main (larger) holes and for the sub (smaller) holes. In the headings, "uniax" means the intermediate structure after the PD stretch, "biax" means the final product. The crotch edge thicknesses are the average thicknesses for a single junction measured. Though there are connected junctions in the biax products of Examples 6 and 7, the biax junction mid-point thickness is express d as the av rage thickness of the mid-points of the two junctions.

Table

Example	Hole shape	PD pitch	SD pitch	SD punch-out, %	Projecting extent (j), mm	b:a	d:c	θ	⊥	X	⌀
1	Fig 1g	38	24	51	1.5	1.6:1	2.0:1	90	0	90	39
2	Fig 1g	38	27	45	1.5	1.5:1	2.0:1	90	0	90	39
3	Fig 2	38	24	51	1.0	1.6:1	2.0:1	67	0	113	33
4	Fig 3	38	24	53	1.5	1.6:1	2.0:1	90	0	90	39
5	Fig 4	38	24	51	1.8	1.6:1	2.0:1	90	0	90	34
6	Fig 7a	38	24	50	1.5	1.6:1	2.0:1	90	0	90	39
7	Fig 8a	46	27	45 main 13 sub	1.5	1.5:1	1.8:1	90	0	90	39

Table (Continued)

Example	a:t	c:t	Starting material thickness (t), mm	Thickness of crotch edge after punching, mm	PD stretch ratio	SD stretch ratio	Distance of SD orientation from junction mid-point, mm	Junction diagonal ratio	Uniax junction mid-point thickness, mm	Uniax % reduction in junction mid-point thickness
1	2.0:1	1.6:1	6.1	5.9	5.0:1	2.7:1	6	0.9:1	5.9	4.1
2	2.5:1	1.6:1	6.0	5.5	5.0:1	2.7:1	7	0.9:1	5.7	4.2
3	2.0:1	1.6:1	6.1	6.0	5.0:1	2.7:1	5	0.9:1	5.8	4.4
4	2.0:1	1.6:1	6.1	6.0	5.0:1	2.7:1	6	0.9:1	5.8	5.2
5	2.0:1	1.6:1	6.1	6.0	5.0:1	2.7:1	5	0.9:1	5.9	3.6
6	2.0:1	1.6:1	6.1	<6.1	5.0:1	1.8:1	n/a	1.0:1	5.9	3.6
7	2.5:1	2.1:1	6.1	<6.1	3.9:1	2.6:1	n/a	1.0:1	n/a	0.8

Table (Continued)

Example	Biax junction mid-point thickness, mm	Biax % reduction in junction mid-point thickness	Biax thickness of thickest crotch edge part	Biax % reduction in thickness of thickest crotch edge part	Biax ridge-line minimum thickness, mm	Biax ridge-line thickness ratio, %	Ratio biax thickest crotch edge part: junction mid-point, %
1	5.8	4.4	5.3	9.8	5.2	90	91
2	5.7	3.7	5.4	3.1	5.4	94	94
3	5.8	4.3	5.0	17	5.0	87	85
4	5.9	3.9	5.5	8.4	5.3	90	93
5	5.9	4.1	5.4	9.7	5.3	89	92
6	5.8	4.9	5.3	11	5.3	89	89
7	5.9	3.3	5.5	8.8	5.5	92	92

Table (Continued)

Example	Uniax PD peak load, kN/rib	Uniax rupture mode ***	Biax PD peak stress, MPa	Biax PD peak load, kN/rib	Biax PD strength, kN/m	Biax weight, g/m²	Biax PD economy rating, kN/m/ kg/m²	Biax PD rupture mode ***	Biax SD peak load, kN/rib	Biax SD strength, kN/m	Biax PD/SD rib strength	Biax PD/SD strength
1	2.58	1	266	2.61	40.8	298	137	1	2.00	10.5	1.3	3.9
2	2.92	1	242	2.93	40.0	309	129	1	n/a	n/a	n/a	n/a
3	2.71	1	268	2.55	39.2	293	134	3	1.99	10.4	1.3	3.8
4	2.67	1	306	2.60	40.6	296	137	3	1.98	10.3	1.3	3.9
5	2.59	1	257	2.53	39.0	290	134	2	1.84	9.6	1.4	4.1
6	2.611	1	243	2.60	61.0	467	131	164	1.90	10.0	1.4	6.1
7	3.092	1	214	3.04	44.0	438	101	1	2.86	15.9	1.1	2.8

*** 1 All strand breaks
2 Mostly strand breaks
3 Mostly ductile junction failures
4 All ductile junction failures

Figures 11 to 15

Figures 11 to 15 are schematic illustrations of known geotechnical structures, in which geogrids 25 in accordance with the invention are used in place of earlier geogrids. In each case, the geogrid 25 is shown with its PD extending across the plane of the paper and its SD extending out of the plane of the paper. For short lengths of geogrid 25, the manufacturing technique could be such that the geogrid has a much greater dimension in the SD than in the PD so that a single width of geogrid extends across a broad part of the face of the geoconstruction.

Briefly:

Figure 11 shows a retained wall 51 formed of full-height panels which can be vertical or inclined by up to 45° to the vertical. The geogrids 25 are in parallel layers and fixed to the wall 51.

Figure 12 shows a retained wall 52 formed of discrete blocks or incremental panels, which wall 51 can be vertical or inclined by up to 45° to the vertical. The geogrids 25 are fixed to the blocks or panels or are secured between or to them in any suitable manner, eg by friction or using mortar or pins or special fixings.

Figure 13 shows the fac of a retained embankment 52 with the geogrids 25 in parallel layers and the end of each geogrid 25 taken up at the face and brought back into the soil, the brought-back part 26 being in contact with the geogrid 25 of the next layer up.

Figure 14 shows a simpler retained embankment 52 construction, with the geogrids 25 terminating at the face.

Figure 15 shows an embankment 52 whose base is stabilised by a geogrid 25. There may be multiple, vertically-spaced layers of geogrid 25 in any suitable arrangement, above the geogrid 25 shown.

*   *   *   *

The disclosures of the patent specifications referred to above are included in this disclosure by reference.

The present invention has been described above purely by way of example, and modifications can be made within the spirit of the invention.

Claims

1. A method of producing a biaxially-stretched plastics material mesh structure having a greater strength in a primary direction (PD) than in a secondary direction (SD) substantially at right angles to the PD, comprising:

providing a plastics starting material which has a thickness (as herein defined) of at least about 2 mm and has a pattern of holes on a notional substantially square or rectangular grid whose axes are substantially parallel to the PD and to the SD respectively, the sides of at least some PD end portions of said holes being defined by crotch-forming zones having protuberances;

applying PD stretch to form oriented PD strands and to apply some orientation to the notional junction zones (as herein defined) so that orientation extends into and through the notional junction zones; and

applying SD stretch with an overall stretch ratio of at least about 1.5:1 (as measured from the mid-point of one notional junction zone to the mid-point of the adjacent notional junction zone in the SD) to form oriented SD strands;

in th mesh structure s produced, the mid-point of the notional junction zone being significantly thicker

than the mid-point of any ori nted strand entering the
notional junction zon , and at least part of the edge of
the crotch interconnecting adjacent sides of adjacent
oriented PD and oriented SD strands being oriented in
the direction running around the crotch, but the
orientation ratio decreasing significantly as one passes
around the crotch edge either from the oriented PD
strand or from the oriented SD strand, the crotch edge
either a) having an unoriented part, or b) the thickness
of the least oriented part of the crotch edge being
reduced, or the length of the least oriented part of the
crotch edge being increased, by no more than about 20%
by the action of stretching, and the action of
stretching not reducing the thickness of any point along
notional lines of maximum thickness on the
biaxially-stretched mesh structure from the mid-point of
the notional junction zone to said crotch edges to such
an extent that the ratio of finished thickness to
starting thickness at that point is less than about 80%
of the ratio of finished thickness to starting thickness
of the notional junction zone mid-point.

2.   The method of Claim 1, wherein the protuberances are
in the plan view shape of the hole.

3.   The method of Claim 2, wherein, as seen in plan view
as one progresses towards the PD end of th hole, each
said crotch-forming zone has:

i) a first part which widens out;

ii) a second part which does not widen out as rapidly as the first part; and

iii) a third part which widens out more rapidly than the second part and terminates the crotch-forming zone.

4. The method of Claim 3, wherein, as seen in plan view as one progresses towards the PD end of the hole:

i) the side of said first part is progressively more inclined to the PD axis and is defined at least in part by a curve which is concave with respect to the hole;

ii) the side of the second part is progressively less inclined to the PD and is defined at least in part by a curve which is convex with respect to the hole;

and

iii) the side of said third part is progressively more inclined to the PD and is defined at least in part by a curve which is concave with respect to th hole.

5.   Th method of any of Claims 2 to 4, wherein th $\underline{b}:\underline{a}$ ratio (as defined herein) is greater than about 1.5:1.

6.   The method of any of Claims 2 to 5, wherein the $\underline{d}:\underline{c}$ ratio (as defined herein) is greater than about 1.5:1.

7.   The method of any of the preceding Claims, wherein the PD stretch is applied with an overall stretch ratio of at least about 3:1 (as measured from the mid-point of one notional junction zone to the mid-point of the adjacent notional junction zone in the PD).

8.   The method of any of the preceding Claims, wherein the SD punch-out (as defined herein) is less than about 60%.

9.   The method of any of the preceding Claims, wherein said plastics material is a polyolefin.

10. The method of any of the preceding Claims, wherein holes having at least one crotch-forming zone as defined in Claim 1 are interspersed in the SD between other holes which do not have a crotch-forming zone as defined in Claim 1.

11. The method of any of the preceding Claims, wherein holes having at least one crotch-forming zone as defined in Claim 1 are interspersed in the PD between other

hol s which d not have a crotch-forming zone as defin d in Claim 1.

12. A biaxially-stretched integral plastics material mesh structure produced by the method of any of the preceding Claims.

13. A biaxially-stretched integral plastics material mesh structure having a greater strength in a primary direction (PD) than in a secondary direction (SD) substantially at right angles to the PD, made from a starting material which has a thickness (as herein defined) of at least about 2 mm, and comprising oriented PD strands and oriented SD strands, interconnected by junctions whose mid-point thickness is significantly greater than the mid-point of any oriented strand entering the junction, adjacent sides of adjacent oriented PD and oriented SD strands being interconnected by crotches whose edges for at least part of their length are oriented with orientation running in the direction around the crotch, the orientation of the PD strands extending into and through the junctions, and the junctions comprising a central zone which is thicker than thinner zones adjacent the ends of oriented PD and oriented SD strands, the junction central zone having a narrow projection at the corner extending outwards betwe n said thinner zones, continuing through the crotch between the oriented PD and oriented SD strands

and running into the crotch dge, with no point on a
notional line of maximum thickness on the mesh structure
from the junction mid-point to the crotch edge having a
thickness of less than about 80% of the thickness of the
junction mid-point.

14. The mesh structure of Claim 13, wherein said
junction interconnects two oriented PD strands entering
the junction from opposite sides and two oriented SD
strands approaching or entering the junction from two
other opposite sides, and the junction central zone is
generally square or rectangular with a said narrow
projection at each corner.

15. The mesh structure of Claim 13, wherein said
junction is connected by non-oriented or low-oriented
material to an adjacent junction in the SD.

16. The mesh structure of Claim 13 or 15, wherein said
junction is connected by non-oriented or low-oriented
material to an adjacent junction in the PD.

17. A method of producing a biaxially-stretched plastics
material mesh structure, substantially as herein
described with reference to any of Figures 1a to 1g,
Figure 2, Figure 3, Figure 4, Figure 5, Figure 6,
Figures 7a to 7f, Figur s 8a t 8e, Figures 9a and 9b or

Figures 10a and 10b of the accompanying drawings, or in any of the foregoing Examples.

18. A biaxially-stretched mesh structure, substantially as herein described with reference to any of Figures 1a to 1g, Figure 2, Figure 3, Figure 4, Figure 5, Figure 6, Figures 7a to 7f, Figures 8a to 8e, Figures 9a and 9b or Figures 10a and 10b of the accompanying drawings, or in any of the foregoing Examples.

19. A method of strengthening soil, comprising embedding in the soil the mesh structure of any of Claims 12 to 16 and 18.

20. A geotechnical construction, comprising a mass of particulate material strengthened by embedding therein the mesh structure of any of Claims 12 to 16 and 18.

3569R

The Patent Office

58

Application No: GB 9524112.1	**Examiner:** J P Leighton
Claims searched: 1-20	**Date of search:** 7 February 1996

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

    UK Cl (Ed.O): B5A(AD31)

    Int Cl (Ed.6): B29C(55/14); B29D(28/00)

Other: Online: WPI

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
X	GB 2256164 A Netlon Ltd. - whole disclosure	1 at least
X	GB 2174332 A P.L.G. Research see hole profiles Figs. 2 & 6-8	"